Analysis and Application of Earned Value Management to the Naval Construction Force

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Analysis and Application of Earned Value Management to the Naval Construction Force

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Abstract

This paper investigates the application of Earned Value Methodology to Naval Construction Force (NCF) projects. Earned Value Management integrates technical performance, cost, and schedule goals into a comprehensive analysis tool. A guide to the elements, metrics, and steps required in implementing an Earned Value Management System is provided from an extensive literature review on the subject matter. Application to the Naval Construction Force is made through comparison with existing project management fundamentals and sample project analysis. While these existing fundamentals include some of the basics components of earned value analysis, a full utilization of the analysis and forecasting techniques afforded by the earned value approach is not in place. Conclusions and recommendations for future research are presented.

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List of Abbreviations and Symbols

ACWP	Actual Cost of Work Performed
ANSI/EIA	American National Standards Institute/Electronic Industries Association
BAC	Budget at Completion
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
C/SCSC	Cost/Schedule Control Systems Criteria
C/SSR	Cost/Schedule Status Report
CAS	Construction Activity Summary
CEC	Civil Engineer Corp
CII	Construction Industry Institute
CPI	Cost Performance Index
CPM	Critical Path Method
CV	Cost Variance
CV%	Cost Variance Percent
DOD	Department of Defense
DSMC	Defense Systems Management College
EAC	Estimate at Completion
ETC	Estimate to Completion
EVM	Earned Value Management
EVMS	Earned Value Management System
LOE	Level of Effort
MD	Manday
NCB	Naval Construction Brigade
NCF	Naval Construction Force
NDIA	National Defense Industrial Association
NMCB	Naval Mobile Construction Battalion
OBS	Organization Breakdown Structure
PERT	Program Evaluation and Review Technique
PMB	Performance Measurement Baseline
PMI	Project Management Institute
SCI	Schedule Cost Index
SITREP	Situation Report
SPI	Schedule Performance Index
SV	Schedule Variance
SV%	Schedule Variance Percent
TCPI	To Complete Performance Index
VAC	Variance at Completion
VAC%	Variance at Completion Percent
WBS	Work Breakdown Structure

1. Introduction

"Earned Value Management is the use of an integrated management system that coordinates work scope, schedule, and cost goals and objectively measures progress toward these goals. Earned Value Management (EVM) emphasizes the planning and integration of a program's technical performance, cost, and schedule, to support program manager's decisions." Figure 1.1 depicts this relationship:[1]

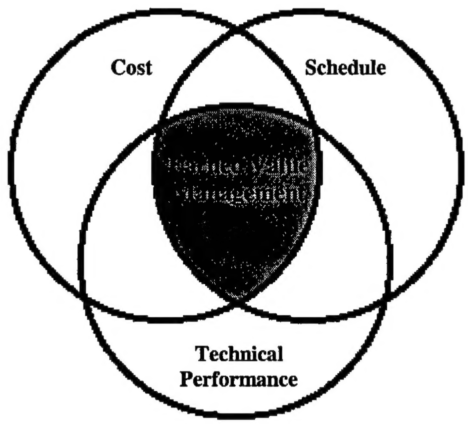

Figure 1.1 – Earned Value Management an Integrating Tool

EVM uses progress against previously defined work plans to forecast such important concerns as estimated completion costs, finish dates, and the effectiveness of corrective action plans. Earned value is the measurement of what was physically received for what was actually spent, or the value of work accomplished.

The concept of earned value has gone by various titles including industrial factory standards, earned value management, performance measurement, the Cost/Schedule Control Systems Criteria (C/SCSC), as well as Program Evaluation and Review Technique (PERT). Regardless of the term used, the focus of earned value has been consistent: "the accurate measurement of 'work in progress' against a detailed plan to indicate what will happen to work on the project in the future."[2]

[1] Defense Systems Management College (DSMC), 2001, p.3
[2] Fleming, Koppelman, 1996, p.13

1.1 Research Objective

The primary objective of this paper is to assemble, organize, and assess the applicability of Earned Value Management to the project management techniques used by the Naval Construction Force. To achieve this objective, the following questions will be addressed:

1. ***What is Earned Value Management?*** Although much has been written concerning this subject, this paper will attempt to distill the published information into a concise description of the techniques and methodology that can be used in applying this concept.
2. ***What steps are necessary to implement earned value analysis?*** From the definition of Earned Value Management that will be provided, a broad overview of the steps necessary to begin analyzing earned value data will be provided.
3. ***Are there metrics or tools from earned value analysis that can be applied to Naval Construction Force project management?*** Finally, this paper will analyze the results of an application of earned value metrics to actual Naval Mobile Construction Battalion projects.

1.2 Research Methodology

To achieve the objectives of this research, a comprehensive literature review was conducted on the topic of Earned Value Management and how to best implement it. Next an application of the concept was made utilizing current Naval Mobile Construction Battalion projects was conducted in order to test the validity of the researched performance metrics. Conclusions and recommendations for future research were developed from this analysis and from personnel experiences.

1.3 Research Organization

This research paper is organized into six chapters that will move the reader from an introduction of earned value management and the processes involved with establishing this

analysis tool, to how it can be utilized by the Naval Construction Force. Projects from two Naval Mobile Construction Battalions will be utilized to highlight the analysis possibilities that could be realized. Finally, the research wraps ups with conclusions and recommendations for future research.

Chapter 1 is an introduction to the subject of Earned Value Management and the objectives of this paper. Chapter 2 details the evolution of Earned Value Management and the basic elements involved in analyzing its data. Chapter 3 builds on the concepts presented and outlines the steps required in implementing an Earned Value Management System. This chapter also presents performance measurement tools for calculating and analyzing project data. In Chapter 4, the focus shifts to the Naval Construction Force and its project management fundamentals. Comparisons are made with these techniques and the earned value approach. In Chapter 5, a practical application of the methodology identified in this paper is presented and reviewed along with challenges that could impede the full implementation of the earned value approach. Finally, Chapter 6 concludes the paper and recommends areas for future research.

2. What is Earned Value Management?

This chapter presents the evolution of Earned Value Management along with an introduction to its key elements and concepts. It summarizes the findings of a literature review on how this management philosophy is described in books, journal articles, papers, and on the Internet.

2.1 Origin and Evolution

Although it has only been of late that the earned value concept has truly gained in prominence, it is a concept conceived by industrial engineers who worked in American factories over a century ago. By converting "planned industry standards" into "earned standards" and then relating them against "actual hours" these engineers began to focus on true cost performance.[3] This distinction forms the basis of earned value management.

The driving force behind the evolution of this technique has been the United States Department of Defense (DOD). In 1958, the U.S. Navy first introduced the Program Evaluation and Review Technique (PERT) as a network-scheduling device for the Polaris Weapons System.[4] By 1962, PERT incorporated resources into its network analysis thereby managing both time and cost.[5] Due to a combination of insufficient computer resources, complexity, and rigorous implementation requirements PERT was essentially abandoned as a management tool by the mid-1960s.[6] However, the significance of PERT was not its technique, but that it used earned value data to monitor the true cost performance during the life of a project.

Realizing the usefulness of earned value data, the U.S. Air Force implemented the first true earned value management approach as part of their Minuteman Program in 1963.[7] One key difference between this approach and the previous PERT techniques was that the Air Force compiled thirty-five criteria defining the minimum requirements of an acceptable project management system. This innovation gave each contractor the flexibility to tailor its individual

[3] Fleming, Koppelman, 1994, p. 24
[4] Department of the Navy (DON), 1958.
[5] Fleming, Koppelman, 1997, p. 13
[6] Fleming, Koppelman, 1996, p. 27
[7] Abba, 1997, p. 59.

system in order to meet contract requirements. Finally, in 1967, the DOD formally issued what was called Cost/Schedule Control Systems Criteria (C/SCSC) as part of DOD Instruction 7000.2.[8]

During the next three decades, significant knowledge was gained regarding the earned value concept using the C/SCSC. Unfortunately, the concepts of earned value remained largely restricted to the acquisition of major systems by the government and were not fully embraced by private industry.[9] By 1994, earned value was being described as one of the most underutilized cost management tools available to project managers.[10] Some of the reasons for this lack of use were excessive checklists and paperwork, specialist acronyms, and rising administrative costs due to over-implementation of the C/SCSC criteria.[11] Some viewed the earned value methodology as excessive "bean counting",[12] a stance resulting from bureaucratic interpretations of the C/SCSC criteria that were slowly increasing the burden on contractor's management systems. With concern rising amongst both private industry contractors and the DOD, the earned value concept was ready for reform.

In order to take Earned Value Management techniques beyond a government mandate, both private industry and the U.S. government strived to make it more user-friendly. In addition to being simpler to use, both parties wanted to make the criteria more compatible with the needs of private industry. As part of a National Defense Industrial Association (NDIA) initiative, private industry took a proactive role in reengineering the original 35 C/SCSC into the Earned Value Management System criteria, which consisted of 32 straightforward guidelines.[13]

In 1997, these 32 criteria were accepted by the DOD and incorporated as part of DOD Instruction 5000.2R.[14] However, in the course of modifying the criteria, two significant shifts occurred. First, it came to be identified more as a project management technique vice a financial management one. Second, the ownership of earned value transferred from the DOD to

[8] Department of Defense Instruction (DODI) 7000.2
[9] Fleming, Koppelman, 1996, p.30
[10] Fleming, Koppelman, 1994, p. 21
[11] Antvik, 1998
[12] Abba, 1997, p.61
[13] Fleming, Koppelman, 1999, p.1
[14] DODI 5000.2R

private industry. To solidify these changes, the Earned Value Management System was adopted as American National Standards Institute (ANSI/EIA) Standard #748 in July 1998.[15]

Today, Australia, Canada, New Zealand, and Sweden have all expressed interest in cooperating with the U.S. in making the concept of earned value a worldwide project management technique. Abba summarizes the evolution and future of earned value management as:

> Nearly 30 years after being introduced as DOD policy, earned value management is seen as a significant reform activity. For people involved in earned value, whether in government, industry, academia, or consulting, these are exciting times. A good idea from three decades ago has been reinvented as a valuable and fundamental tool.[16]

The viability of earned value management has been tested, improved, and adopted by both the Government and private industry. With increasing emphasis and widespread use, it truly is a technique that project managers everywhere can use.[17]

2.2 Traditional Cost Management vs. Earned Value

In describing earned value, it is probably best to first compare it with a more customary cost management technique. Under what Fleming and Koppelman describe as traditional cost management, a two-dimensional approach is employed: the simple relation of planned costs to the actual costs as shown in Figure 2.1.[18] Using this approach, it is difficult if not impossible to determine the true cost performance, since a comparison between the budgeted plan and actual costs can be faulty and misleading.[19]

[15] Fleming, Koppelman, 1996, p. 32
[16] Abba, 1997, pg. 61
[17] Fleming, Koppelman, 1996, p. 32
[18] Fleming, Koppelman, 1994, p. 22
[19] Fleming, Koppelman, 1996, p. 18

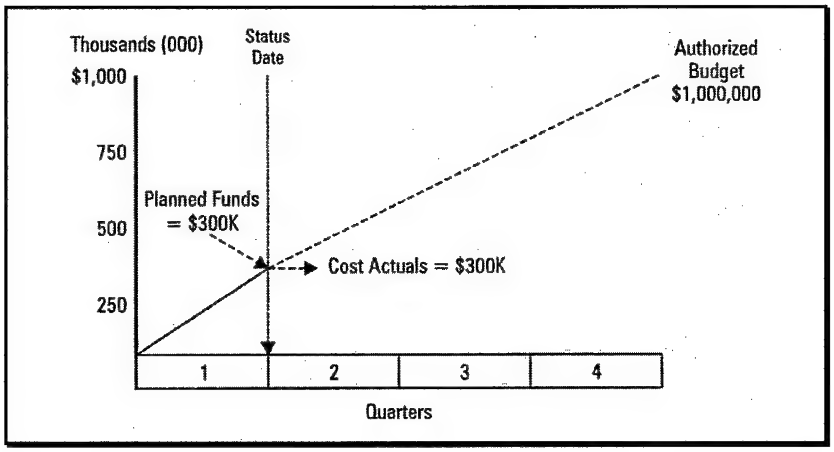

Figure 2.1 – Traditional Cost Management: Plan versus Actual Costs[20]

In contrast, earned value project management adds a third dimension: the amount of work accomplished or the value of the work performed.[21] With this third dimension, a project manager has a better measure of "what they got for what they paid." By comparing the earned value to the planned cost for a given period, the project manager can now identify whether the project is ahead or behind schedule. Similarly, by comparing the earned value to the actual costs expended during a given period, a determination of whether the project is underrunning or overrunning its budget can be made.[22] See Figure 2.2 below for an illustration of this concept.

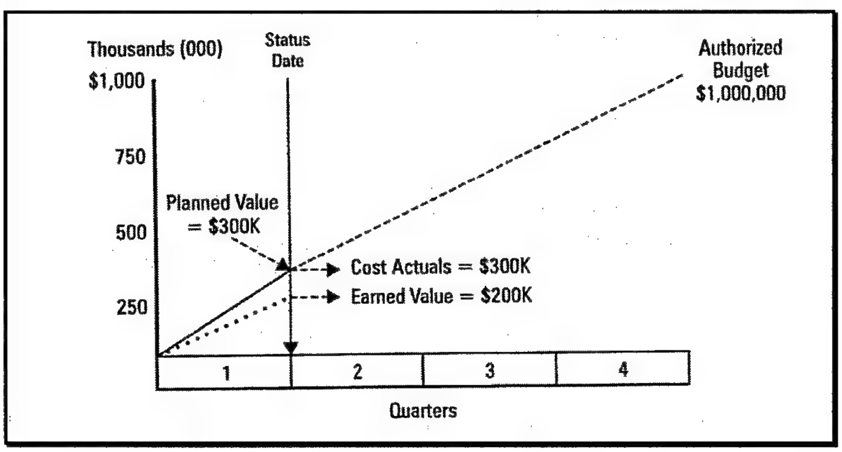

Figure 2.2 – Earned Value Project Management: Three Dimensional[23]

[20] Fleming, Koppelman, 1996, p. 18
[21] Fleming, Koppelman, 1994, p. 22
[22] Christensen, 1994, p. 30
[23] Fleming, Koppelman, 1996, p. 19

2.3 Elements of Earned Value

With the introduction of earned value data, the three primary elements for deriving performance in earned value project management can be defined. The three elements are:

1. Planned Value → Budgeted Cost for Work Scheduled, (BCWS)
2. Actual Costs → Actual Cost of Work Performed, (ACWP)
3. Earned Value → Budgeted Cost of Work Performed, (BCWP)[24]

2.3.1 Budgeted Cost of Work Scheduled

The BCWS, or "Planned Value", is the sum of the budgets, usually expressed in dollars or man-hours, for all planned work scheduled to be accomplished within a given period.[25] One common method to develop BCWS is to use a computerized scheduling system and apply budget estimates to individual schedule activities. Based on the time when the activities are scheduled to occur, the application produces a histogram and/or a curve that displays the summation of the activity budgets for the work scope in predetermined time periods.[26] When calculating the BCWS two additional parameters to review are Performance Measurement Baseline and Budget at Completion.

2.3.1.1 Performance Measurement Baseline

The *Earned Value Management Implementation Guide* defines the Performance Measurement Baseline (PMB) as, "The time-phased budget plan against which contract performance is measured."[27] It is the sum of all activities' BCWS for each time period, calculated for the total project duration. When graphed, the PMB forms the familiar S-curve for planned work. It is important to note that the BCWS is a segment of the PMB and as such represents all the tasks scheduled for accomplishment within a given period.[28]

[24] Christensen, 1999, p. 284
[25] PMI, 1996, p. 160
[26] Short, 1993, p. 36
[27] DOD, 1996, p. 10
[28] DOD, 1996, p. 10

2.3.1.2 Budget at Completion

Budget at Completion (BAC) is the cumulative sum for all Budgeted Costs of Work Scheduled and represents the original estimate of the cost for a project.[29] It denotes the endpoint of the time-phased PMB curve.

2.3.2 Budgeted Cost of Work Performed

The *Earned Value Management Glossary* defines BCWP, commonly referred to as the "Earned Value", as "the sum of the approved budgets, usually in terms of dollars or man-hours, for activities or portions of activities completed during a given period."[30] The various methods for calculating earned value are discussed in the next section of this paper.

2.3.3 Actual Cost of Work Performed

The ACWP are the costs, usually in terms of dollars or man-hours, actually incurred and recorded for accomplishing the tasks performed on a project within a given time period.[31] As such, it is representative of all accrued expenditures incurred in completing the work.[32] This includes charges for goods and services received and other assets acquired, such as invoices for work, material delivered, progress payments and fees/profit allocable to the contract.[33]

2.4 Summary

In this chapter, the history and evolution of Earned Value Management was outlined with comparisons made with traditional cost management. With earned value management, a key third element is introduced, namely the "earned value" for the work performed. From the definitions provided for the basic elements, a further look at the steps to establishing a management system based on these elements can be made.

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[29] Air Force Materiel Command (AFMC), 1998, p. 39-26c
[30] EVM Homepage: Glossary, p.1
[31] AFMC, 1998, p. 39-26a
[32] PMI, 1996, p. 108
[33] Valkenhoff, 1981, p. 222

3. Establishing an Earned Value Management System

With an understanding of the basic elements in place, the process of initiating an Earned Value Management System (EVMS) can be discussed. As previously mentioned, 32 criteria have been internationally accepted for use in establishing an EVMS. These criteria are expressed in fundamental terms and provide contractors the flexibility to optimize their management system while remaining fully accountable for its effectiveness.[34] The guidelines are structured in five areas common to a contractor's management processes:[35]

- Organization
- Planning, Scheduling, and Budgeting
- Revisions
- Accounting
- Analysis

Each of the criteria addresses a principle necessary for effective management of a project. "For example, one criterion requires that each element of work on the project have a schedule. Another requires that each element of work on the project have a budget. A sufficient management control system that promotes proper planning and integration of work on a project is vital to the effective use of EVM."[36]

The entire set of 32 criteria that have been adopted can be found in Appendix A. However, this research paper will not review and analyze each criteria, instead it will focus on a broader overall view of the major categories to describe the implementation process. It is the author's belief that this will provide the reader with a simpler understanding of the steps required.

3.1 <u>Organization</u>

The project manager's ability to define and control a project's full scope of the work is a key element to its success.[37] The scope of a project, however, can be different amongst the various parties involved. While all might agree on what the outcome should be, each

[34] DOD, 1996, p.4
[35] DODI 5000.2R
[36] Delaney, 2000, p3

individual's specific involvement varies with the nature of the work they are to perform. A subcontractor, for example, understands his scope of work in a much narrower degree of detail than the prime contractor does. As scope is defined, it is important that all involved have a clear understanding of the tasks necessary to complete the project.

"When there is poor scope definition, final project costs can be expected to be higher because of the inevitable changes which disrupt project rhythm, cause rework, increase project time, and lower the productivity and morale of the workforce."[38] If the scope of work is not defined accurately or communicated to all involved, then the outcome of the project will not be as expected. Consequently, with no baseline against which the scope can be measured, it is not possible to distinguish scope changes from project development.[39] Plainly put, without a well-defined scope of work, one cannot distinguish between agreed upon work and any additional work that may arise. Therefore, it is essential to properly define the projects total scope of work in order to establish a baseline against which to utilize earned value analysis.[40]

3.1.1 Work Breakdown Structure

During the 1960's, the momentum to develop a tool to help project managers define a project in a cohesive way gave rise to the development of the Work Breakdown Structure (WBS).[41] John Mansuy's article "Work Breakdown Structure: A Simple Tool for Complex Structures" offers the following:

> "A Work Breakdown Structure is a tool that helps you plan, organize, and control any project. In this age of complex management techniques, it is often overlooked because of its simplicity. Yet, this simplicity makes the WBS a powerful project management tool that can be used with little financial or personnel resources."[42]

While a Statement of Work defines the overall requirements for a project, the WBS provides the basic framework for identifying each element of the project in increasing levels of detail. The *Guide to the Project Management Body of Knowledge* defines a WBS as:

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[37] PMI, 1996, p.52
[38] CII, 1986, p.45
[39] Kraus, 1992
[40] Fleming, Koppelman, 1994, pp. 22-24
[41] DSMC, 2000, p. 3-8
[42] Mansuy, 1991, p. 15

> "A task-oriented "family tree" of activities, which organizes, defines and graphically displays the total work to be accomplished in order to achieve the final objectives of a project. Each descending level represents an increasingly detailed definition of the project objectives."[43]

Breaking the project down into manageable work elements allows these elements to be used throughout the project for planning, scheduling, budgeting, performance evaluation, and most importantly, for earned value analysis. See Figure 3.1 for an example WBS.

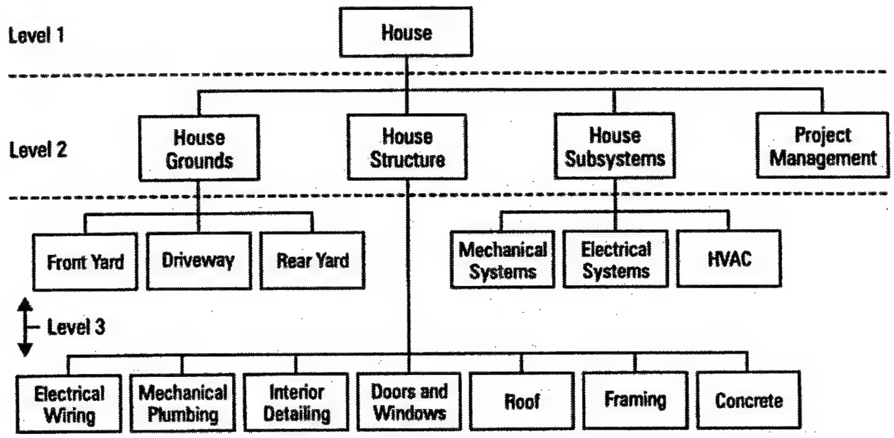

Figure 3.1 – Work Breakdown Structure[44]

3.1.2 Organization Breakdown Structure

An essential component of the earned value concept is that responsibility be assigned for each element of the WBS.[45] To facilitate this, an Organization Breakdown Structure (OBS) is used. The OBS defines the organizational elements responsible for performance of the project work. It is a hierarchical depiction of the management organization required to perform the work outlined on the Work Breakdown Structure.[46] In essence, the OBS should reflect the way in which a contractor has organized the people who will accomplish the work. The interrelation of the WBS and OBS is shown in Figure 3.2 on the following page.

[43] PMI, 1987
[44] Fleming, Koppelman, 1996, p. 55
[45] Wilkens, 1997, p.5
[46] Fleming, Koppelman, 1996, p. 201

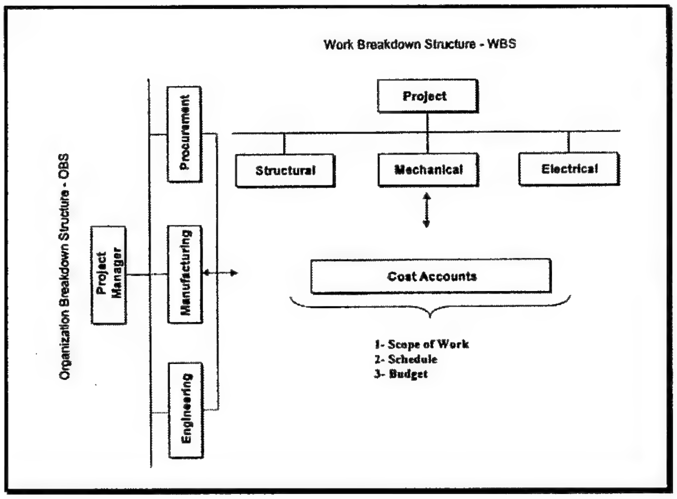

Figure 3.2 – Interrelation of WBS and OBS

3.1.3 Control Accounts

At the intersection of the WBS and the OBS, where responsibility has been established for work activities, one can find the control account (also known as the cost account in C/SCSC criteria). This resulting intersection creates a performance measurement unit that combines the schedule, cost, and technical aspects of the project.[47] Department of Defense Instruction 5000.2R defines the control account as,

> "A management control point at which actual costs may be accumulated and compared to the budgeted cost of work performed. A control account is a natural control point for cost and schedule planning and control, because it represents the work assigned to one responsible organizational element on one work breakdown structure element."[48]

Control accounts provide a correlation between the amount of work that is planned and the resources available to accomplish that work. Each control account generally contains three pieces of information: the scope of work for the associated WBS element, its schedule, and its budgeted cost.[49] The development of these components will be discussed in the next section.

[47] Fleming, Koppelman, 1996 p. 115
[48] DODI 5000.2R
[49] Fleming, Koppelman, 1995, p. 40

3.2 Planning, Scheduling, and Budgeting

Following organization, the next step incorporates the planning of project activities within the control accounts, logically sequencing them into a project schedule, and then assigning an estimated budget to that activity.

3.2.1 Planning and Scheduling of Work Packages

Work packages are defined as natural subdivisions of a control account that represent a particular job assignment or work activity. Work packages also represent the basic building blocks used in planning, controlling, and measuring project performance.[50] As outlined in the *Earned Value Management Implementation Guide*, a work package should have the following characteristics:

- It represents units of work at levels where work is performed.
- It is clearly distinguished from all other work packages.
- It is assignable to a single organizational element.
- It has scheduled start and completion dates and, as applicable, interim milestones, all of which are representative of physical accomplishment.
- It has a budget or assigned value expressed in terms of dollars, man-hours, or other measurable units.
- Its duration is limited to a relatively short span of time or it is subdivided by discrete value milestones to facilitate the objective measurement of work performed.
- It is integrated with detailed engineering, manufacturing, or other schedules.[51]

Since the work package is the lowest level at which performance data is normally analyzed, it is important to balance its duration and scope against the length of the reporting cycle. When longer duration work packages are used, it is harder to determine status due to the volume of work involved. On the other hand, when work packages are defined at too low a level of detail, the administrative burden involved with tracking the work can be excessive.

[50] PMI, 1996, p. 61
[51] DOD, 1996, p.11

Finally, for each work package, the milestones, technical performance goals, or other indicators that will be used to measure performance should be identified in the initial planning phase.[52]

3.2.2 Scheduling

It is essential that a project employing the earned value concept have at a minimum a master project schedule, thereby establishing a baseline against which future performance can be compared.[53] The master schedule and any subordinate schedules for a project should be related to the work levels identified by the WBS, as shown in Figure 3.3. Although any scheduling technique will work, a critical path method (CPM) is generally utilized.[54] With the time-phased sequencing that the CPM affords, the budgeted value for each planned work package can be aligned to establish the performance measurement baseline. With any project, there will always be a tradeoff between cost, schedule, and performance. "The best schedule supports the best tradeoff between these competing demands, taking into account the risks that are associated with each tradeoff and the impact on the overall program."[55]

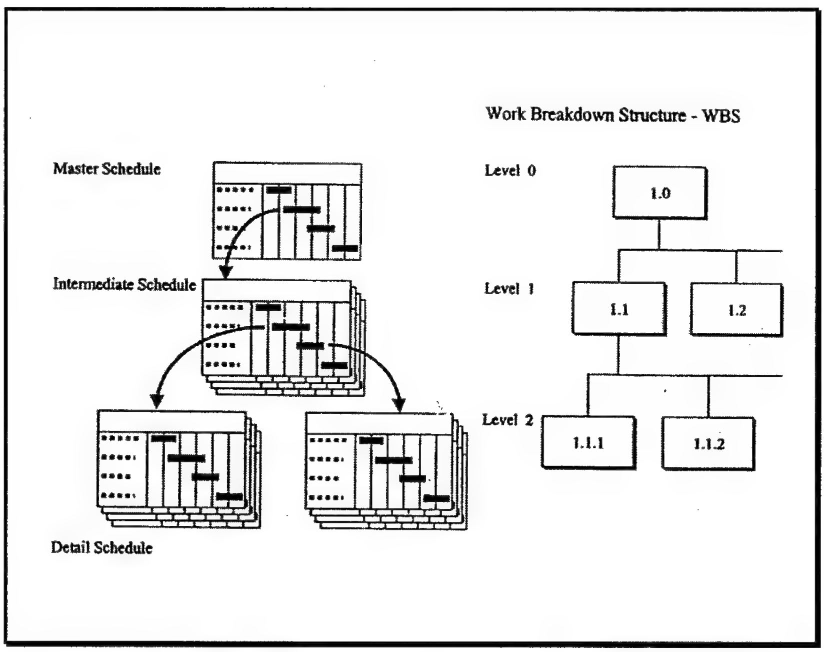

Figure 3.3 – Relation of Schedule to Work Breakdown Structure[56]

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[52] AFMC, 1998, p. 39-6d
[53] Fleming, Koppelman, 1996, p. 67.
[54] Fleming, Koppelman, 1996, p. 67.
[55] DSMC, 2000, p. 3-13
[56] Dua, 1997, p. 6

3.2.3 Estimate and Budget Project Resources

After planning and scheduling the activities necessary to complete the project, the next step is to establish a budget the work. In order to develop a budget, one must forecast what resources the project will require, the required quantities, when they will be needed, and how much they will cost.[57] Depending on the resources to be tracked, the budget can be expressed in any monetary, labor, or other measurable unit. Planning and budgeting can be done at both the summary and at the detail level. Therefore, two different strategies exist for generating a budget: top-down and bottoms-up methods.

In the top-down method, budgets are initially set at a higher level and then broken down into budget estimates for specific tasks and work packages. This process continues until the project is broken down to the lowest level work package.[58] However, according to Fleming and Koppelman, "...the project baseline needs to be created from detailed bottoms-up planning."[59]

In the bottoms-up method, the schedules and budgets for individual WBS elements are constructed thereby creating a more accurate budget when compared to the top-down method. These resulting budgets are collected, or "rolled up", to establish the final budget for the project.[60]

3.2.4 Establish Baseline

One of the key factors in utilizing Earned Value Management is the creation of a performance baseline. When a project is in process, costs are incurred due to the consumption of resources related to the completion of work. To determine how well the project is doing, a comparison against the original plan is required. Having planned the work packages with respect to time and budget, a baseline can be created as the basis for this comparison. As previously identified, this time phased budget plan is known as the performance measurement baseline.

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[57] Meredith, 1995, p.289
[58] Meredith, 1995, p. 292
[59] Fleming, Koppelman, 1996, p.75
[60] Meredith, 1995, p. 292

3.3 Revisions

Although the scope of work and the work breakdown structure for a project may be well defined, it is rare that the baseline at the end of the project will be the same as at the beginning. There are many factors encountered throughout construction of a project that can affect this baseline. A typical cause of a necessity to revise the baseline is a change to the scope of work. It is essential that changes to the baseline be documented and controlled in order to distinguish between the original and new work if the need should arise.[61]

3.4 Accounting

The incorporation of actual cost data into an Earned Value Management System is referred to as accounting. The primary concern with the accounting aspect of the earned value concept is the accumulation and reporting of costs accurately. [62] Costs on a project can be incurred through labor, material, equipment, subcontracts and other direct or indirect costs. In preparation for analysis, costs must be correctly applied to the proper work packages to facilitate summarization by both the WBS and OBS.[63]

3.5 Analysis

The last phase of Earned Value Management is to monitor performance against the baseline for the duration of the project. To monitor this progress, variances and indices should be calculated and analyzed by management. Periodically, a forecast of the final costs, the efficiency required to achieve these costs, and an estimated completion date should be made and compared with project goals. By interpreting the results of this analysis and the forecasts, management action may be necessary in order to keep the project's final cost and schedule within desired goals.

As defined earlier, the key elements of earned value, namely BCWS, BCWP, and ACWP, are determined for each task and a comparison of these elements provides a measure of schedule and cost performance. These measurements must be treated with caution, however, as

[61] Fleming, Koppelman, 1996, p. 109
[62] DSMC, 2001, p. 55

they are only indicators of the efficiency or performance of a project. Therefore, they should only be used as one of the many factors on which project managers base their decisions, and then only after interpreting all pertinent information.

When analyzed properly, performance measures indicate where shortfalls are occurring and where extra resources, management action, or other support is required in order to overcome the problem. In addition, they can also simultaneously foreshadow what may happen to a project if such remedial actions are not taken.[64]

In the following subsections, the various methods for calculating earned value, variances, performance indices, and overall status indicators will be provided. The discussion on analysis will conclude by detailing the forecasting tools available from earned value data.

3.5.1 Measuring Earned Value

Similar to the budget, earned value can be measured in dollars, man-hours, or any other measurable unit. There are several methods for measuring earned value dependent on the type of work being performed. The type of effort involved with the work activity separates the different methods into three categories, which will be identified. The three categories are: [65]

- Discrete Effort
- Apportioned Effort
- Level of Effort

3.5.1.1 Discrete Effort

Discrete effort project tasks have a definable scope and objectives that can be scheduled, and have progress measured against.[66] The discrete effort methods of measuring earned value will now be described in more detail.

Fixed Ratio Formula Method – Perhaps the easiest method to understand and to implement is a fixed ratio that adds to 100 percent. Common uses of this method are with a 0/100, 25/75,

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[63] DSMC, 2001, p. 55
[64] Fleming, Koppelman, 1996 p. 111 – 119.
[65] Harroff, 2001.
[66] Harroff, 2001.

or 50/50 ratio. These methods allow a given percentage complete when an activity starts and the remainder when its finish date is reported. For example, with the 25/75 method, 25% is reported complete at the start, and 100% is reported at the finish. However, the accuracy of this method as a progress measure clearly declines for longer work packages, since there is a measure of progress only in the period the work starts and the period the work ends. Interim periods will show no progress; hence, this method will not be consistent with the BCWS for longer durations.[67]

Weighted Milestone Method – For durations greater than two periods, the use of a weighted milestone method for planning resources and measuring progress works well. This method has the advantage of showing physical accomplishment of milestones leading to completion of the work package. Each milestone is assigned a specific budgeted value, which will be earned upon physical completion of the task.[68]

While this is one of the preferred methods for calculating earned value, it requires significant upfront planning in order to establish the necessary milestones for each task. Therefore, care should be taken when using this method to ensure that the milestones are not artificial, but rather a natural subdivision of the work.

Percent Complete Method – If a task is greater than two months in duration and discrete interim milestones cannot be identified, another technique that can be selected is the percent complete method. This method is most desirable when the percent complete can be calculated based on measurable parameters such as length, square feet, or cubic yards of work accomplished. When such parameters are not available, this method can be questionable since estimates are frequently made on a subjective basis.[69]

Percent Complete with Milestone Gates Method – An alternative to the percent complete method is to introduce milestone "gates" that allow subjective estimates up to a point at which a designated performance mark must be passed. This method provides a balance between the

[67] Fleming, Koppelman, 1996, p 89
[68] DSMC, 2001, p.114
[69] DSMC, 2001, p. 115

initial planning required with the weighted milestones and the possible subjectivity with the percent complete method.[70]

Earned Standards – The earned standards method is useful for production-type work and is perhaps the most sophisticated method of computing earned value. Standards of performance based on historical cost data, time and motion studies, etc. are used to measure the earned value. However, no standard for computing the earned value with this method works best in every situation, and often several are utilized. A recommended approach is to allow several standards to be used initially with a management consensus required to determine which one is eventually selected.[71]

Equivalent Unit Method – This method is based on measuring the number of units or items that have been completed and comparing the result to the total number of units or items that have to be completed. This approach is best suited for manufacturing or activities with repetitive elements.[72]

3.5.1.2 Apportioned Effort

The second of the three categories with which to measure earned value is apportioned effort. Apportioned effort is useful for tasks whose planning and performance has a direct relationship to another task. The earned value for the apportioned task is driven by the status on the linked task. Quality control and inspections are examples of apportioned effort.[73]

3.5.1.3 Level of Effort

The final category is level of effort. Level of effort is work scope of a general or supportive nature for which performance cannot be measured or is impractical to measure. Because these tasks are more time driven than task driven, the earned value always equals the planned value, regardless of the work done.[74] Therefore, level of effort scopes of work do not

[70] Fleming, Koppelman, 1996, p 91
[71] Fleming, Koppelman, 1996, p 93
[72] Fleming, Koppelman, 1996, p 92
[73] Harroff, 2001
[74] Harroff, 2001

have a schedule variance and produce very misleading cost variances. For this reason, this method is generally not recommended to track earned value.[75]

3.5.2 Variances

It is safe to say that no plan, schedule or estimate is exact and thus variances are certain to occur.[76] A variance is the difference between the planned, scheduled, or actual costs.[77] "Typical causes of variances include poor initial planning or budgeting, changes to the project's scope, changes in technology related to the project, changes to the delivery schedule, changes to labor contracts, changes to material costs, inflation, and measurement error."[78] The presence of significant variance notifies management that something needs to be examined and proper corrective action taken. With earned value analysis, three main variances can be determined. The first two, Schedule Variance and Cost Variance, will be defined in this section. The last, the Variance at Completion, will be discussed after introduction of additional terminology.

3.5.2.1 Schedule Variance (SV)

Schedule variance provides a representation of schedule status, indicating whether budgeted work is being accomplished as planned.[79] It is the difference between the earned value and the planned value as indicated in Equation 3.1:

$$SV = \text{Earned Value} - \text{Planned Value} = BCWP - BCWS$$

Equation 3.1 – Schedule Variance

The schedule variance may be calculated on current or cumulative data, with the cumulative schedule variance being used most often for analysis purposes. A positive variance indicates favorable schedule performance since the amount of work performed is greater than what was scheduled. Conversely, a negative variance means less work was performed than planned and the project is behind schedule.[80] It is important to note, however, that at contract

[75] Fleming, Koppelman, 1996, p. 95
[76] Valkenhoff, 1981, p.223
[77] Microsoft, p. 307
[78] Christensen, 1993, p. 17
[79] AFMC, 1998, p. 39-27.2
[80] DSMC, 20001, p. 136

completion the schedule variance is always zero because all scheduled work has been performed.

3.5.2.2 *Schedule Variance Percent (SV%)*

Although, it does not introduce new data, the schedule variance percent is significant in that it normalizes the SV by comparing it to the total budget. Equation 3.2 summarizes the method for calculating the SV%. A positive SV% indicates that the project or activity may be ahead of schedule and a negative SV% means the project may be behind schedule. As discussed for SV, the SV% is most meaningful when calculated using cumulative data and when the analysis includes a detailed review of all performance measurements.[81]

$$SV\% = \frac{SV}{\text{Planned Value}} = \frac{SV}{BCWS}$$

Equation 3.2 – Schedule Variance Percent

3.5.2.3 *Cost Variance (CV)*

Cost Variance measures the difference between the cost that was planned for a given task and the cost that was actually incurred in performing the task.[82] As such, it is the difference between the earned value and the actual costs as shown in Equation 3.3:

$$CV = \text{Earned Value} - \text{Actual Costs} = BCWP - ACWP$$

Equation 3.3 – Cost Variance

The cost variance may be calculated on either cumulative or current data. As with the schedule variance, the cumulative cost variance is most often used for analysis purposes. A positive cost variance indicates that the contractor is accomplishing work for less than was budgeted. On the other hand, a negative CV means more money was spent for the work accomplished than was originally planned.[83] An example calculation for both the SV and the CV is presented in Figure 3.4.

[81] AFMC, 1998. p. 39-27.4b
[82] DOE, 2000, p. 10-6
[83] AFMC, 1998. p. 39-27.1

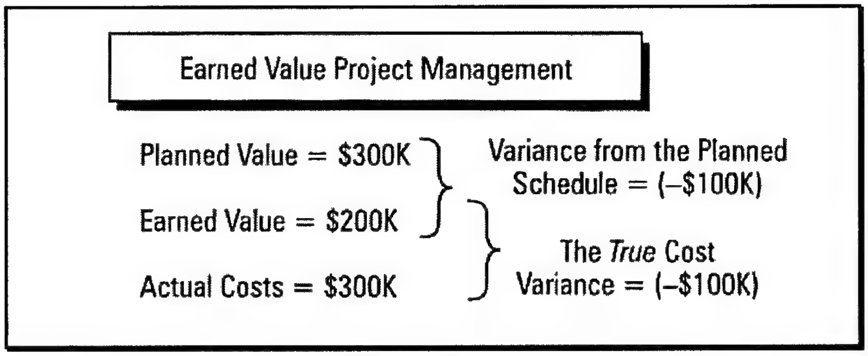

Figure 3.4 - Schedule and Cost Variance Example[84]

3.5.2.4 Cost Variance Percent (CV%)

This measure expresses the cost variance as a percentage relative to the amount of work accomplished, as shown in Equation 3.4. A negative CV% means the project is over cost by the calculated percentage. The CV% value should be compared with the CPI for the same period to verify a cost overrun or underrun situation.[85] For example, a CPI of .8 indicates poor cost performance; therefore, a negative CV% would be expected.

$$CV\% = \frac{CV}{\text{Earned Value}} = \frac{CV}{BCWP}$$

Equation 3.4 – Cost Variance Percent

By analyzing the cause of a variance, the project manger can identify significant differences between the planned and actual cost performance. Generally, a negative variance can be viewed as bad and a positive variance as good, although this may not always be the case. For example, a positive variance may be caused from the contractor's front-loading of his schedule of values, thereby robbing resources intended for later tasks. Another indicator of problems during variance analysis is if no variances are reported over several periods. This can indicate a lack of tracking on the contractor's part since it is difficult to forecast work with such accuracy.

During analysis, if the cumulative CV and SV both reflect negative trends, the task being performed may be very complex, the contractor may have underestimated the scope of the task,

[84] Fleming, Koppelman, 1996, p. 20
[85] AFMC, 1998. p. 39-27.4a

or the method of calculating earned value may not fully take credit for work as it is performed. Positive values for both variances may be due to good contractor performance, a simple task, or an overly generous contractor estimate for the effort.[86] A graphical representation of both the Schedule Variance and the Cost Variance is provided in Figure 3.5:

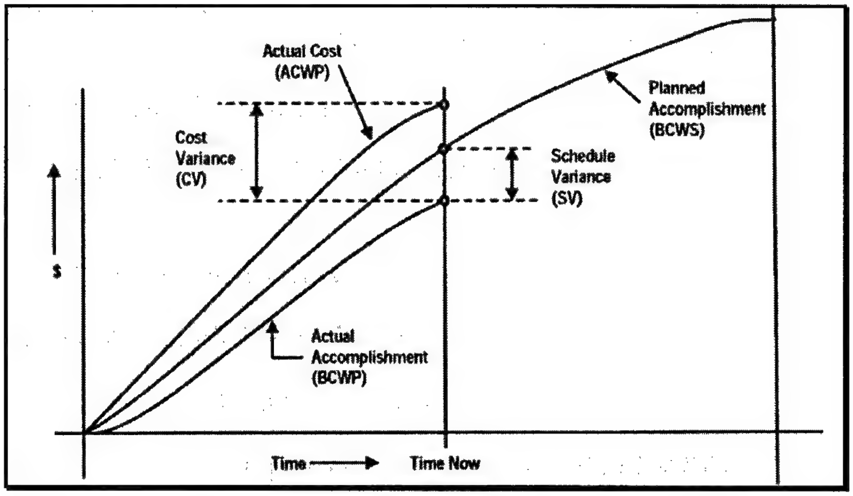

Figure 3.5 - Graphical View of Schedule and Cost Variances[87]

[86] AFMC, 1998. p. 39-27.4
[87] DOE, 2000, p. A-1

3.5.3 Performance Indices

"Performance indices show the percentage of variation, between planned and actual performance, for the current period, cumulative to date, and at the completion of a task."[88] The Schedule Performance Index and the Cost Performance Index are calculated to provide an efficiency factor for the work accomplished in either the current period or a cumulative timeframe. The analysis techniques that produce these two performance indices will now be described.

3.5.3.1 Schedule Performance Index (SPI)

The SPI indicates the ability of the contractor to control the project schedule and compares the budget for those tasks scheduled to be accomplished as of the status date with the budget for the work that was actually accomplished as of that date.[89] It is calculated as the ratio of earned value to planned value as shown in Equation 3.5:

$$\text{SPI} = \frac{\text{Earned Value}}{\text{Planned Value}} = \frac{\text{BCWP}}{\text{BCWS}}$$

Equation 3.5 – Schedule Performance Index

An SPI of 1.0 indicates that the project is on schedule and performing at 100% efficiency. An index greater than 1.0 shows an ahead of schedule situation, while one below 1.0 reflects a behind schedule condition. Figure 3.6 below provides an example.

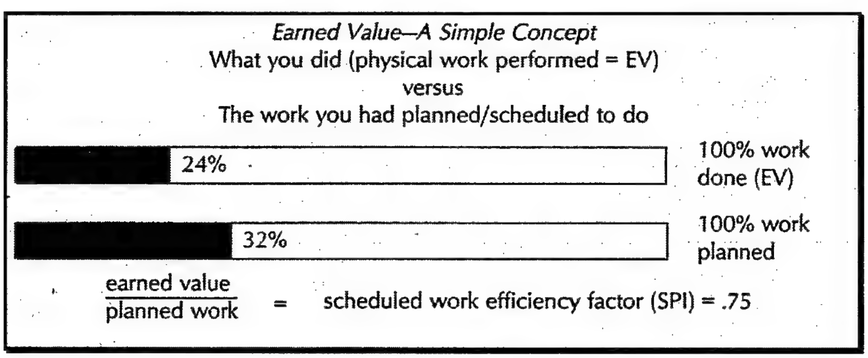

Figure 3.6 - Schedule Performance Index[90]

[88] Harroff, 2001
[89] Fleming, Koppelman, 1996, p.113
[90] Fleming, Koppelman, 1994, p. 22

3.5.3.2 Cost Performance Index (CPI)

The CPI indicates the ability of the contractor to control cost and compares the budget for those tasks that have been accomplished with the actual cost of accomplishing the tasks.[91] It is calculated as the ratio of earned value to actual costs as shown in Equation 3.6:

$$CPI = \frac{\text{Earned Value}}{\text{Actual Costs}} = \frac{BCWP}{ACWP}$$

Equation 3.6 – Cost Performance Index

The CPI measures the cost efficiency with which work has been accomplished. A CPI of 1.0 indicates that for every actual dollar spent, a dollar's worth of work was accomplished. An index above 1.0 indicates a cost underrun or higher efficiency, while an index below 1.0 reflects performance below what was expected. "A CPI less than 1.0 is rarely improved upon, and usually proves to be unrecoverable."[92] An example calculation follows in Figure 3.7.

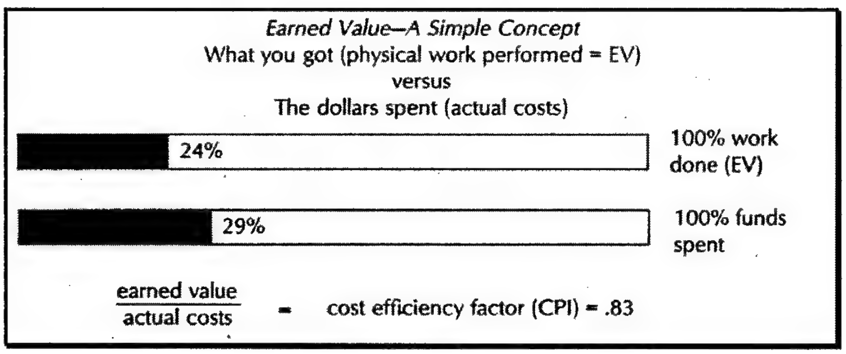

Figure 3.7 Cost Performance Index[93]

[91] AFMC, 1998. p. 39-27.7
[92] Fleming, Koppelman, 1996, p.114
[93] Fleming, Koppelman, 1994, p. 22

With the major components of earned value performance measures defined, one can examine the various scenarios that exist. With an unchanging baseline, six scenarios exist for a given project as illustrated in Figure 3.8.[94] By referencing this figure, a quick determination can be made as to the budget and schedule status.

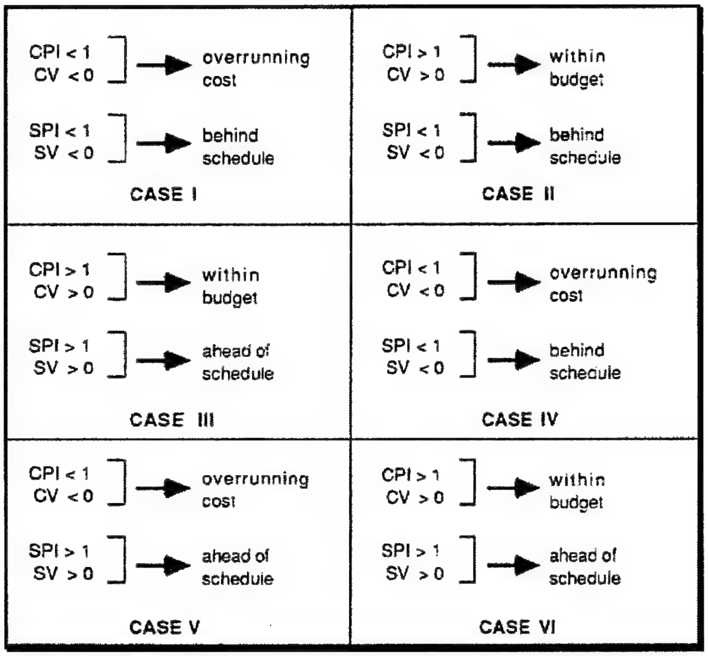

Figure 3.8 - Six Scenarios of Earned Value Analysis

[94] Singh, 1991, p. 42

3.5.4 Overall Project Status Indicators

In addition to the SPI and the CPI, three other calculations that can be made in order to determine efficiencies on a project are percent complete, planned percent complete, and percent spent.

3.5.4.1 Percent Complete

One of the more recognized performance calculations in the construction industry is percent complete. It is the relationship between the budgeted value for what has been completed to date and the total budget,[95] as shown in Equation 3.7.

$$\text{Percent Complete} = (\text{BCWP} / \text{BAC}) \times 100$$

Equation 3.7 – Percent Complete

3.5.4.2 Planned Percent Complete

In conjunction with percent complete, the planned percent complete provides a comparison for what was scheduled to date.[96] Equation 3.8 shows the relationship:

$$\text{Planned \% Complete} = (\text{BCWS} / \text{BAC}) \times 100$$

Equation 3.8 – Planned Percent Complete

3.5.4.3 Percent Spent

A comparison of the percent compete with the percent spent indicates performance spend efficiency. The percent spent indicator is calculated as the ratio of the actual costs to the budget at completion,[97] as shown in Equation 3.9:

$$\text{Percent Spent} = (\text{ACWP} / \text{BAC}) \times 100$$

Equation 3.9 – Percent Spent

[95] DSMC, 2001, p. 139
[96] DSMC, 2001, p. 139
[97] DSMC, 2001, p. 138

3.5.5 Forecasting

In addition to analyzing variances and performance indices for trends to determine problems in the execution of a project, earned value data can also be used as a forecasting tool. During execution of a project, forecasting has two objectives: to provide a forecast for the outcome of the project based on current status and trends; and second, to highlight trends or potential budget deviations that require management control.[98] When forecasting, one has to take into account the time phase of the project. At the beginning of a project, uncertainty about the outcome is higher than at the end of the project. This uncertainty results in a range of possible final projections. With earned value data, however, early predictions have proven to be reliable. As described by Fleming and Koppelman:

> "Perhaps the single most compelling reason to employ earned value is that it enables the project manager to be able to 'statistically' forecast the (probable) final cost, and schedule results on the project…from as early as the 15 percent completion point. With earned value, the project does not have to wait until it is 90 percent spent to know that it has a problem. The 90 percent point is too late to alter the project's final course. Earned value provides an 'early warning' message to management in time to take corrective action, in time to influence the final results with aggressive action."[99]

"Successful forecasting is based on a foundation of a good baseline plan, tracking performance against that plan, and the commitment of upper management to use and act on the performance data."[100] From earned value data and the performance measurements identified, an Estimate at Completion, To-Complete Performance Index, and the Estimated Completion Date can be forecasted.

3.5.5.1 Estimate at Completion

The Estimate at Completion (EAC) is an important tool used in forecasting because it gives an indication as to where the project cost is heading. Christensen presents many methods to forecast the EAC, however they all take the basic form shown in Equation 3.10:

[98] McMullan, 1996, p. 20.1
[99] Fleming, Koppelman, 1996, p. 127
[100] Smith, 1999, p.9

$$EAC = ACWP_{CUM} + \frac{(BAC - BCWP_{CUM})}{P_f}$$

Equation 3.10 – Estimate at Completion

In the above equation, since the budget for the remaining work is frequently understated, a performance factor is used to adjust it upward. There are four types of performance factors (P_f) that can be used, all of which assume that past efficiency will continue in the future.[101] The four factors are:

1. Schedule Performance Index
2. Cost Performance Index
3. Composite Index
4. Schedule Cost Index (SCI)

Since the SPI and CPI have already been discussed, the Composite Index and the Schedule Cost Index will be reviewed. The Composite Index is the weighted sum of the SPI and CPI, where the weights add to one. The value assigned to these weights should be based on experience and historical data from the project. The Schedule Cost Index is the product of the SPI and CPI. Equations 3.11 and 3.12 depict these two performance factors respectively.[102]

$$\text{Composite Index} = (W_1 \times SPI) + (W_2 \times CPI), \text{ where } W_1 + W_2 = 1$$

Equation 3.11 – Composite Index

$$\text{Schedule Cost Index (SCI)} = SPI \times CPI$$

Equation 3.12 – Schedule Cost Index

In deciding which factor to use, the CPI based performance factor has proven to be the most useful since the quantity of known data increases as the quantity of work decreases.[103] However, through the use of multiple factors, a range of EACs can be produced thereby increasing the likelihood that the final EAC will be included. The low end of this predicted range is usually produced using a special case for the performance factor. With a P_f of 1.0, the assumption is that all future work will be done as planned and the current cost variance will

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[101] Christensen, 1993, p. 18
[102] Christensen, 1999, p. 290
[103] Christensen, 1993, p. 21

remain constant.[104] The high end of the range is generally calculated using the SCI performance factor.[105]

3.5.5.2 *Variance at Completion*

With EAC defined, the last variance can now be calculated. The Variance at Completion (VAC) is determined by comparing the budget at completion with the latest estimate at completion as expressed in Equation 3.13:

$$VAC = BAC - EAC$$

Equation 3.13 – Variance at Completion

Again, another way at looking at this variance is to express it relative to the original estimate for the total cost of the project. Equation 3.14 shows the formula for calculating the Variance at Completion Percent.

$$VAC\% = VAC / BAC$$

Equation 3.14 –Variance at Completion Percent

With both the VAC and the VAC%, a positive value indicates that, if current performance continues, the project will be completed below cost. If the result is a negative value, then an overrun situation at project completion can be expected.[106]

Regardless of the method used in calculating the EAC, the value should be carefully reviewed with consideration given to the following:

- Past performance
- Costs incurred to date
- Assessment of tasks remaining
- Future economic conditions
- Cost and Schedule Variance
- Expected future efficiency
- To-Complete Performance Index

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104 Fleming, Koppelman, 1996, p. 133
105 Fleming, Koppelman, 1999, p. 290
106 AFMC, 1998. p. 39-27.3

The last consideration, the To-Complete Performance Index, is a tool that can be utilized to test the reasonableness of the forecasted EAC.

3.5.5.3 *To-Complete Performance Index*

Whereas the SPI and CPI indicate past performance efficiency, the To-Complete Performance Index (TCPI) indicates the cost efficiency factor that must be attained if the remaining work is to be completed within a financial goal. This financial goal can be the total budget, the forecasted EAC, the contract price, or any value less the actual costs that have been incurred to date.[107] Therefore, the TCPI represents the relationship between the work remaining and the funds remaining to complete the project. The TCPI formula with the EAC as the financial goal is shown in Equation 3.15:

$$TCPI_{EAC} = \frac{\text{Work Remaining}}{\text{Funds Remaining}} = \frac{BAC - BWCP_{CUM}}{EAC - ACWP_{CUM}}$$

Equation 3.15 – To-Complete Performance Index

A TCPI greater than 1.0 indicates that future efficiency will need to be greater than planned, while a figure less than 1.0 indicates future efficiency can be less than planned to achieve the financial goal. Christensen notes that for a project more than 20% complete, if the difference between the $TCPI_{EAC}$ and the CPI_{cum} is more than ±10%, the EAC has probably been understated.[108]

3.5.5.4 *Estimated Completion Date*

A forecast of the Estimated Completion Date can be determined by graphically examining the earned value and planned costs. As shown in Figure 3.9, by measuring the time distance from the point on the earned value curve that corresponds with the status date, horizontally to the planned value curve, the schedule variance can be expressed in units of time. By applying this variance to critical path information, a prediction of the potential completion date for the project can be made.[109]

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[107] DSMC, 2000, p. 140
[108] Christensen, 1993, p. 21
[109] Fleming, Koppelman, 1996, p. 139

When making this prediction, it is essential to consider the total float of the project. By accomplishing non-critical activities before their planned start date, it is possible to earn more than what was scheduled. The result of this will be a distortion of the schedule variance and of the project's progress. Therefore, use of the schedule variance as a time predictor should be coordinated with the critical path of the project.

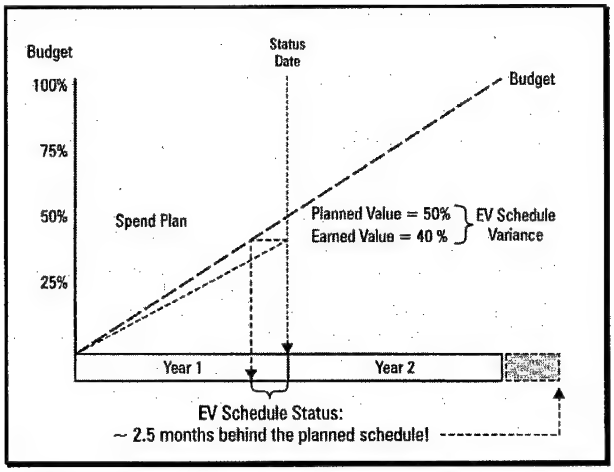

Figure 3.9 - Forecast of Scheduled Completion Date

3.6 Summary

In this chapter, the general steps required to implement an Earned Value Management System were introduced and discussed. First, the necessity to properly organize the project scope with a Work Breakdown Structure was pointed out. Next, the need to assign responsibility and the ways in which the Organization Breakdown Structure accomplished this were reviewed. The planning, scheduling, and allocation of a budget to work packages and their role in forming the Performance Measurement Baseline was presented. This chapter then proceeded to describe the many methods that exist in calculating earned value for work activities in progress. Finally, various performance measures and forecasting methods that can be utilized when performing earned value analysis were detailed. Figure 3.11 below summarizes the earned value parameters reviewed in this paper.

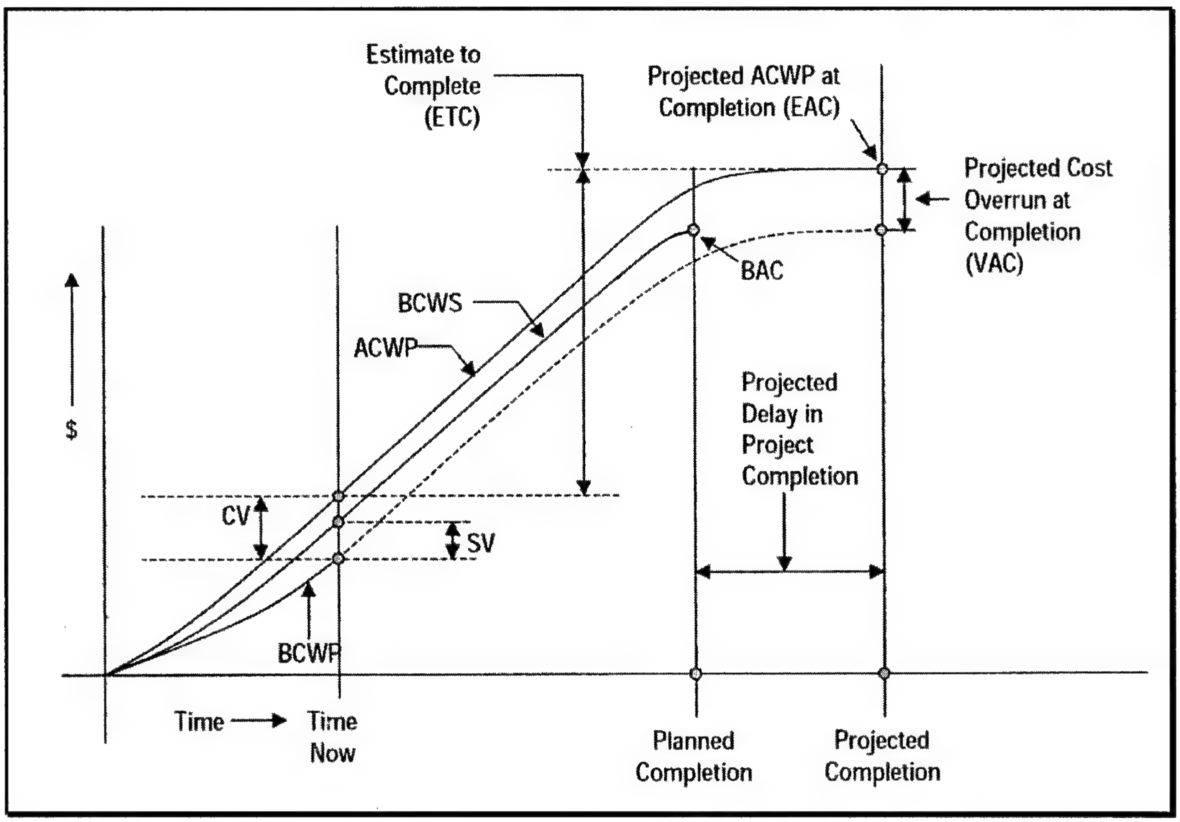

Figure 3.10 - Earned Value Parameters[110]

[110] DOE, 2000, p. A-2

4. Naval Construction Force Project Management

Before applying the earned value concept to Naval Construction Force (NCF) project management, it is necessary to first review the planning and execution phases utilized throughout the NCF in construction operations.

4.1 NCF Overview

The Naval Construction Force refers to a group of naval organizations, which possess the capability to construct, maintain, and operate, both in wartime and in peacetime a myriad of facilities in support of the U.S. Navy and the U.S. Marine Corps. The mission of the NCF has been defined as:

> With Compassion for others – we build, we fight – for peace with freedom. We provide the Navy, Marine Corps, Unified CINCS, and other customers with rapid contingency response, quality construction, disaster recovery support, and humanitarian assistance.[111]

Table 4.1 provides a listing of the type and the number of units that make up the NCF.

Table 4.1 – Units of the NCF[112]

Type of Seabee Organization	Total Number	Total Active	Total Reserve
Naval Construction Brigade	2	2	0
Naval Construction Regiment (Homeport)	2	2	0
Naval Construction Regiment (Line)	6	2	4
Naval Mobile Construction Battalion	20	8	12
Naval Construction Force Support Unit	2	0	2
Underwater Construction Team	2	2	0
Amphibious Construction Battalion	2	2	0
Construction Battalion Maintenance Unit	2	0	2
Construction Battalion Unit	19	19	0

All of these NCF units are comprised of officers of the Civil Engineer Corp (CEC) and enlisted personnel, commonly referred to as Seabees, trained in construction skills.[113] While construction planning and execution is a common practice throughout each of the units, the

[111] Department of the Navy (DON) OPNAV 5450.46K, 1999, p. 5
[112] DON, 1997.

application of the earned value concept for this research will be centered on the Naval Mobile Construction Battalion (NMCB).

4.1.1 Naval Mobile Construction Battalions

Naval Mobile Construction Battalions (NMCBs) provide highly skilled construction support to Navy, Marine Corps, and other forces in military operations. This mission is met through the construction and maintenance of base facilities, the repair of battle-damaged facilities, and by conducting limited defensive operations as required. In addition to standard wood, steel, masonry and concrete construction, NMCBs also perform specialized construction such as water well drilling and rapid runway repair. In times of emergency or disaster, NMCBs can also conduct disaster control and recovery operations.[114]

In peacetime, NMCBs complete a rotation cycle every 14 months. Seven months are spent at a homeport location and the other seven months on deployment. Currently, the eight active duty NMCBs are split between the homeport locations of Port Hueneme, CA and Gulfport, MS and four overseas deployment sites: two in the Atlantic at Roosevelt Roads, Puerto Rico and Rota, Spain, and two in the Pacific at Guam and Okinawa. Various evolutions during this cycle prepare, evaluate and maintain the Battalion's readiness for not only responsive military construction support, but also defensive combat and disaster recover operations.[115]

4.2 Project Planning

Good construction planning and estimating procedures are essential to the ability of a Battalion to provide quality construction. Construction management in an NMCB is comprised of three levels as shown in Figure 4.1.

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[113] Naval Facilities Engineering Command (NAVFAC) P-315.
[114] DON OPNAV 5450.46K, 1999, p. 5
[115] DON, 1995, p II-3

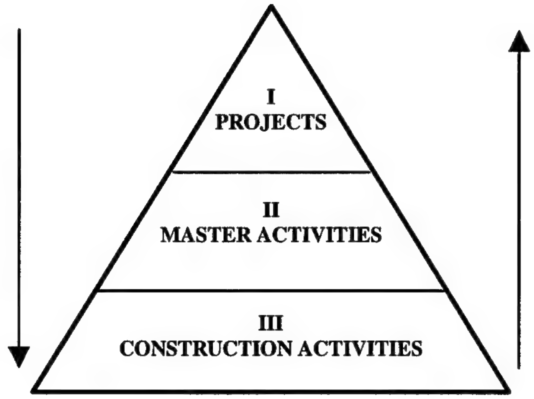

Figure 4.1 – Seabee Multi-Level Construction Management[116]

The above diagram represents that planning is accomplished as a top-down, bottoms-up cycle. Once initiated at a generic project level, planning proceeds to the detailed level before eventually rolling back up into a finalized project package. Further detail as to the amount of information entailed at each level will be covered under the scheduling section of this chapter.

4.2.1 Fundamentals of Seabee Construction Management

Construction management in the Seabees is based on Critical Path Method (CPM) scheduling and is nearly identical to construction management techniques used in the private construction industry. One of the biggest advantages to using CPM analysis is the outstanding training value it affords the project crewleader. As defined by the *Operations Officer Handbook*, NCF project management fundamentals can be categorized into the following steps:

- **Step 1. Develop construction activities** – After careful review of the plans and specifications, the first step is to break the job down into discreet activities. Construction activities are generally less than 15 days in duration and require the same resources throughout. As a rule, an activity should be created for any function that consumes or uses direct labor resources.

- **Step 2. Estimate construction activity requirements** – For each construction activity, resource requirements need to be identified and evaluated. To track these resources, a Construction Activity Summary (CAS) sheet is used to list all

[116] Civil Engineer Corp Officer School (CECOS), 1997, p. I-1

of the material, tool, equipment, and manpower requirements along with safety, quality control, and environmental concerns.

- **Step 3. Development of the logic network** – The logic network is the basic management tool for control, monitoring, and distribution of all resources that are directly related to time. In the planning stage, this logic network is a pure dependency diagram in that all activities are listed in the order they must be accomplished, without regard to particular construction preference.

- **Step 4. Schedule construction activities** – Upon finalizing the logic network, the next step is to determine estimated start and finish dates for each activity based on the sequence and durations of the construction tasks. A critical path is identified to help focus management attention on those activities that cannot be delayed without impacting the project completion date.

- **Step 5. Resource Management** – Resource tracking and control are crucial elements in the successful execution of a project. The project crewleader must ensure that all necessary resources are available when required. Additionally, once on site, resources must be controlled to ensure their productive employment. Proper attention to resource allocation and leveling, the matching of construction activities scheduled to the resources available, will assist in meeting this goal.[117]

4.2.2 Detailed Planning

Having outlined the general fundamentals used by the NCF in planning, a presentation of the detailed planning sequence will further explain the generation of a finalized project strategy. Table 4.2 outlines the project planning milestones from the *Seabee Crewleader's Handbook* that form the backbone of NCF project planning. Figure 4.2 presents these steps in an easy to follow flowchart.

[117] NAVFAC 5200.2B, p. II-6

Table 4.2 – NMCB Project Planning Milestones

1.	Designate Crewleader and Planning Team	13.	Complete Construction Activity Summary Sheets
2.	Pre-Planning Conference	14.	Develop Level III Network
3.	Review Plans and Specifications	15.	Input Network into Computer
4.	Identify Long Lead Materials	16.	Resource Level Project
5.	Identify Required Skills and Training	17.	Develop Level III Bar Chart
6.	Complete Project Scope Sheet	18.	Complete Master Activity Summary Sheets
7.	Complete Master Activity Listing	19.	Develop Level II Bar Chart
8.	Develop Rough Level II Bar Chart	20.	Consolidate Tool Requirements
9.	Develop Level II Logic Network	21.	Consolidate Equipment Requirements
10.	Generate Construction Activity Listing	22.	Consolidate Safety Plan
11.	Conduct Material Take-offs	23.	Consolidate Quality Control Plan
12.	Develop Bill of Materials	24.	Prepare Project Briefing for Chain of Command

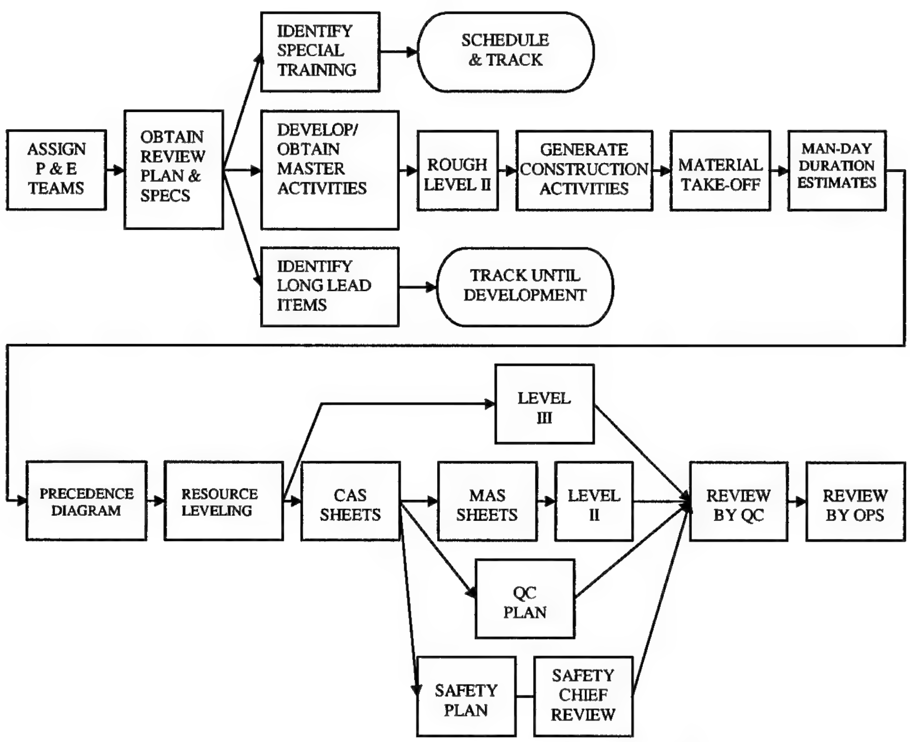

Figure 4.2 – Project Planning Flowchart[118]

[118] DON, 1995, p. 2-5

The results of each of these steps are maintained throughout the life of the project in the project package, a collection of all the information required to plan, schedule, monitor, and execute a project.[119] Beyond identifying in detail the steps involved in planning an NCF project, perhaps the most important outcomes of this process are the generation of the Construction Activity Summary (CAS) sheets, the project schedule, and the allocation of resources.

4.2.3 Construction Activity Summary Sheets

As previously identified, a CAS sheets is used to list all of the material, tool, equipment, and manpower requirements along with safety, quality control, and environmental concerns. Also included are the scheduled start and finish dates for each activity. Just as work packages are the lowest level element of the WBS, a CAS sheet summarizes the lowest level element in the NCF project planning. Through the proper use of the CAS sheet, the project crewleader can greatly reduce the chance of the project being impacted due to a lack of resources. The CAS sheets are designed to be standalone in that all pertinent information, notes, and calculations done during the planning and estimating stages are documented. Therefore, practically all construction effort in the Seabees is driven from the information contained on the completed CAS sheets.[120]

4.2.4 Construction Scheduling

Crucial to a workable project schedule is the proper, logical sequence of activities and good realistic durations.[121] Once outlined, the project schedule is displayed and tracked utilizing a bar chart. Although precedence networks are the primary scheduling tool used in the NCF, the ease of use and quick presentation of project status are two benefits gained by utilizing the bar chart.[122]

[119] CECOS, 1997, p. I-5
[120] CECOS, 1997, p. 2-12
[121] PMI, 1996, p. 52
[122] Ahuja, 1994, p. 46

As discussed, Seabee project planning occurs at three distinct levels that are most readily apparent through the project schedules.

4.2.4.1 Level III schedule

The most in depth of the three schedules is the Level III, as it represents the detailed execution plan for a particular construction project. It designates construction activities, identifies required resources, shows relationships and dependencies amongst activities, and identifies the critical path. Updated project status is maintained continuously on the jobsite as reflected on the Level III bar chart.[123]

4.2.4.2 Level II schedule

At any time during a deployment, a NMCB may be working on 30 or more individual projects. A condensed project schedule, the Level II, that only lists the master activities, aids in the management of all NMCB network schedules. Additionally, the Level II contains the plot of all planned work thereby forming the project baseline against which all future progress is measured. The Level II schedule provides a broader view for determining if a project is on schedule, and indicates what particular areas are going well or need greater emphasis.[124]

4.2.4.3 Level I schedule

For top-level management, the Level I schedule is a consolidated graphic representation of all projects tasked to a NMCB, either planned or in progress at a given site. While this integrated project schedule is a rather broad-brush tool, it does indicate particular problems on an individual project or at a certain detachment site that might require reallocation of resources from one project to another.[125]

[123] DON 5200.2B, 1999, II-5
[124] DON 5200.2B, 1999, II-5
[125] DON 5200.2B, 1999, II-5

4.2.5 Budgeting of Resources

Vice tracking all project costs as a dollar figure, NCF projects utilize labor mandays as the primary unit of measure. Performance measurements and analysis of project status are made through examination of earned mandays, expended mandays, and estimated mandays. A brief explanation of how mandays and activity durations are calculated will be provided to aid in the understanding of Seabee project tracking.

The primary reference for Seabee manday estimates is a manual called the *Seabee Planner's and Estimator's Handbook.* This manual lists how many man-hours it takes to complete one unit of work for various tasks and is based on historical data from past Seabee projects. The total estimated mandays (MDs) for an activity are calculated by using Equation 4.1.

$$\text{MDs} = \text{QTY of WORK} \div \text{UNIT SIZE} \times \text{MHRS PER UNIT} \div 8 \times \text{DF}$$

Equation 4.1 – Manday Calculation

In the equation, a Delay Factor (DF) is utilized to adjust the values from the *Seabee Planner's And Estimator's Handbook* for particular jobs site conditions and is calculated using an average of eight Production Efficiency Factors (PEF)[126], as shown in Equation 4.2.

$$\text{DF} = 67 / \text{PEF}_{\text{AVG}}$$

Equation 4.2 – Seabee Delay Factor

The intent of a Production Efficiency Factor is to adjust for factors that will make a project crew more or less productive than the average worker identified in the *Seabee Planner's And Estimator's Handbook.* Table 4.3 on the following provides a guide for determining the subjective values for the eight Production Efficiency Factors.

[126] CECOS, 1997, p. 2-5

Table 4.3 – Production Efficiency Factor Guide

	LOW PRODUCTION 25 35 45	AVG PRODUCTION 55 65 75	HIGH PRODUCTION 85 95
1. WORK LOAD	CONSTRUCTION REQ'T HIGH, MISC. OVERHEAD HIGH	CONSTRUCTION REQ'T AVG, MISC. OVERHEAD AVG	CONSTRUCTION REQ'T LOW, MISC. OVERHEAD LOW
2. SITE AREA	CRAMPED WORK AREA, POOR LAYDOWN/ACCESS	WORK AREA LIMITED, AVG LAYDOWN/ACCESS	LARGE WORK AREA, GOOD LAYDOWN/ACCESS
3. LABOR	POORLY TRAINED/MOTIVATED CREW	ADEQUATELY TRAINED/MOTIVATED CREW	HIGHLY TRAINED/MOTIVATED CREW
4. SUPERVISION	POORLY TRAINED/MOTIVATED OR INEXPERIENCED	ADEQUATELY TRAINED/MOTIVATED EXPERIENCED	HIGHLY TRAINED, MOTIVATED, AND EXPERIENCED
5. JOB CONDITION	HIGH-QUALITY WORK REQ'D, SHORT FUSE	AVG QUALITY WORK REQ'D, ADEQUATE TIME	ROUGH/UNFINISHED WORK REQ'D, WELL PLANNED
6 WEATHER	ABNORMAL HEAT, RAIN, OR COLD	MODERATE RAIN, HEAT, OR COLD	FAVORABLE RAIN, HEAT, OR COLD
7. EQUIPMENT	POOR COND., MAINT., REPAIR, OR APPLICATION	FAIR COND., MAINT., REPAIR, OR APPLICATION	GOOD COND., MAINT., REPAIR, OR APPLICATION
8. TACTICAL/ LOGISTICAL	SLOW SUPPLY, FREQUENT TACTICAL DELAYS	NORMAL SUPPLY, FEW TACTICAL DELAYS	GOOD SUPPLY, NO TACTICAL DELAYS

From the estimate for the mandays to complete the desired task, the budget is allocated for each construction activity via the CAS sheet. By rolling the construction activities into a project schedule, a performance baseline is produced against which future progress can be measured.

4.3 Project Monitoring and Reporting

Once the project baseline is in place and execution of the construction project begins, the continued success of the project depends on efficient monitoring and regular updating of the project schedule. To accommodate this, monitoring and analysis of project progress is completed bi-weekly during an NMCB deployment. This section will identify the Situation Report, and the methods utilized in analyzing project performance.

4.3.1 Situation Reports

A Battalion submits a Situation Report (SITREP) on a monthly basis to higher headquarters to report the progress of their construction tasking. The accuracy of this SITREP is a reflection of how well the crewleaders have planned the projects work activities,

documented actual labor expenditures, and how management guided implementation of the work plan. In determining the project status for the SITREP, the following are analyzed:

- Estimated Mandays
- Earned Mandays
- Expended Mandays
- Mandays Remaining
- Scheduled Percent Complete
- Actual Percent Complete

4.3.2 Estimated Mandays

Estimated mandays are the planned value for work to be accomplished and are established during the previously identified planning phases for a NMCB project. Similar to the Budgeted Cost of Work Scheduled, they form the basis of the performance measurement baseline against which future progress is measured. Since project planning is completed before a NMCB deploys, knowledge of on-site conditions is limited thus affecting accuracy of initial project estimates. For this reason, approximately 45 days into the deployment, a complete review of performance to date will be conducted. During this 45-day review, adjustments to the project schedule baseline are allowed in order to account for any unforeseen conditions or start up inefficiencies. Afterwards, the project baseline is firm and the Battalion is committed to meeting the scheduled project completion dates.

4.3.3 Earned Mandays

Earned mandays, similar to the Budgeted Cost of Work Performed, are a reflection of the planned work that has been accomplished. For construction activities in progress, the typical method of calculating earned mandays is by utilizing the percent complete method. When available, the earned value of the work in progress is measured on parameters such as length, square feet, or cubic yards of work accomplished. When these parameters are not available, the crewleader makes a subjective estimate of the amount of work completed.

4.3.3.1 Mandays Remaining

When describing earned mandays, it is important to discuss the concept of mandays remaining. Mandays remaining represent how much planned work remains to be done on the project. They are calculated as the difference between the budget at completion, the original

estimate for the planned work, minus the mandays earned to date. This calculation is similar to the Estimate to Completion forecast made in Earned Value Management.

4.3.4 Expended Mandays

Expended mandays represent the actual mandays required to complete an activity. As such, they are equivalent to the Actual Cost of Work Performed in an Earned Value Management System. In the Seabees, timecards are utilized to record mandays expended on a construction project. Through their use, the efficiency and accountability of a project crew can be monitored.[127]

It is important to note that expended mandays are not used in calculating the project percent complete and, therefore, should not be confused with earned mandays. Expended mandays should be used for insight as to why a project may be behind schedule or what activities were under or overestimated. At the end of deployment, the expended mandays on each project are collected for historical data to be used in future NCF planning.

4.3.5 Scheduled Percent Complete

The scheduled percent complete, or estimated work-in-place percent complete, is similar to the performance measurement baseline. As such, it represents the time-phased estimate of the earned mandays for the project. Once established, the scheduled percent complete baseline can only be revised at the 45-day review or in the event of an approved change to the scope of work.

4.3.6 Actual Percent Complete

The actual percent complete, or earned work-in-place (WIP) percent complete, is a measurement of the planned work that has been accomplished to date and is compared to the scheduled progress. In an earned value project management, this value is similar to the Budgeted Cost of Work Performed. It is calculated by first determining the weighted percent for each master activity, which is the ratio of the estimated mandays for that activity over the total project mandays estimated. Next, by taking the product of this weighted percent and the

determined percent complete for each master activity, the actual project percent complete can be calculated.[128]

4.3.7 Analysis of Project Performance

From the techniques identified in measuring project performance on a NMCB project, analysis of the data can now occur. By comparing the scheduled percent complete and the actual percent complete, a determination of whether the project is ahead or behind schedule can be made. This analysis should take into account crew efficiency and their availability factor. The availability factor accounts for crewmembers that are not available as planned for in the scheduled baseline. Some of the major reasons for non-availability are illness, disciplinary actions, watches/duties, medical/dental visits, and administrative matters.[129] Typical availability factors on NMCB projects vary between 0.75 and 0.85.[130] The following guidance is utilized when analyzing project performance data:

- If estimated mandays equal actual/expended mandays and the project is behind schedule, the manday estimate is inaccurate and/or the crew is inefficient.
- If estimated mandays equal actual/expended mandays and the project is ahead of schedule, the manday estimate may have been too high and/or the crew is very efficient.
- If the actual/expended mandays are more than the estimated mandays and the project is on schedule, the manday estimates may have been too low.
- If the estimated mandays are greater than actual/expended mandays, the crew is not meeting the planned availability factor, regardless of the project status. Adjustments are necessary to ensure crews get to the work site.[131]

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[127] CECOS, 1997, p. 8-1
[128] CECOS, 1997, p. 8-1
[129] DON 5200.2B, p. IV-11
[130] CECOS, 1997, p. 2-10
[131] DON 5200.2B, p. IV-12

4.4 Summary

From an overview of the management techniques used in the Naval Construction Force, an indication of an Earned Value Management System exists. After outlining the construction management fundamentals and delving into the detailed planning steps, similarities with the defined earned value methodology were presented. Namely, the five categories associated with establishing an EVMS system do exist in NCF project management.

However, after a review of the manuals dedicated to project planning in the Seabees, it is apparent that the performance metrics that are frequently identified with earned value analysis are not readily used. The author believes that by not exploiting all the available data and analysis techniques afforded by the earned value methodology, valuable project management tools are lost.

5. Practical Application of Earned Value Management

This chapter examines and presents the results of a practical application of Earned Value Management to NMCB projects. Specific problem areas that may be met in the utilization of these techniques are also identified. In reviewing this application, projects were selected from two Battalions who had recently completed overseas deployments. Two projects from NMCB SEVEN's deployment to Puerto Rico; and two from NMCB FOUR's deployment to Okinawa were selected.

5.1 Application of Earned Value Concepts

Before applying the concepts learned from earned value management, a review of the data gathered from each Battalion was conducted. One of the first items that observed was the difference in the Level IIs utilized for project management. Although the general format and data were similar, there were differences in the metrics displayed beyond the standard estimated, earned, and expended mandays and calculations for percent scheduled, percent earned, and percent expended. The intent of this paper is not to point out one Battalion's techniques over another, but rather to provide an example of the different management approaches that could be unified with earned value analysis.

For example, NMCB FOUR calculates a current working estimate at completion. This is the same as forecasting an EAC with a performance factor of 1.0. Other calculations utilized for managing their projects were: Manday Efficiency per period, Percent Ahead/Behind per period, and cumulative Percent Ahead/Behind. These measures are analogous to a period, vice cumulative, Cost Performance Index, Schedule Variance Percent per period, and a cumulative Schedule Variance Percent.

As a review of earned value and NCF project management terminology, Table 5.1 aligns similar terms to aid in the understanding of the information in this chapter.

Table 5.1 – Comparison of Earned Value and NCF Terminology

EARNED VALUE	NCF
Planned Value BCWS	Estimated Mandays
Earned Value	Earned Mandays
Actual Costs ACWP	Expended Mandays
Performance Measurement Baseline	Scheduled Percent Complete Curve
Percent Complete	Percent Complete Work-in-Place (WIP)
Planned Percent Complete	Percent Scheduled
Percent Spent	Percent Expended
Estimate at Completion	Current Working Estimate
Estimate to Completion	Mandays Remaining
Budget at Completion	Tasked Mandays
Cost Performance Index	Manday Efficiency
Schedule Variance Percent	Percent Ahead/Behind

5.2 Methodology

In applying the metrics identified with earned value analysis, the following were calculated for the each project:

- Schedule Variance
- Cost Variance
- Schedule Variance Percent
- Cost Variance Percent
- Schedule Performance Index
- Cost Performance Index
- Estimates at Completion
- To-Complete Performance Indices
- Variance at Completion
- Variance at Completion Percent

For EAC, forecasts where made utilizing each of the identified performance factors including the special case of $P_f = 1.0$. After calculating the performance measures, plots were made for the forecasted Estimates at Completion, as well as the calculated cumulative SV, CV, SPI, and CPI versus time. In all plots, time was representative of the number of bi-weekly reporting periods since the 45-day review. Additionally, since the Level IIs only included planned value and earned value plots, a plot of the actual costs was made. The results of these calculations can be found in Appendix C.

5.3 Review of Application

The application of earned value analysis to the sample NMCB projects afforded new means by which to analyze each project's status. In addition to the plots of the earned value, planned value, and actual cost data, the graphs of the cumulative CPI, SPI, CV, and SV provided good indicators of project performance to date. The analysis also highlighted performance trends that would provide valuable information to management.

After an initial, negative performance trend, most projects tended to level out before eventually gaining in efficiency. At the beginning of a deployment, project crews need to familiarize themselves with the project and on-site conditions. Additionally, project support and material supply issues may not be entirely resolved and therefore can affect performance. After achieving a certain level of efficiency, an increase can generally be expected towards the end of the deployment as emphasis on project completion increases. Through careful review of these issues and tracking of the performance trends during the execution of a project, management action can be focused as required. Figures 5.1 and 5.2 are examples of this performance trend:

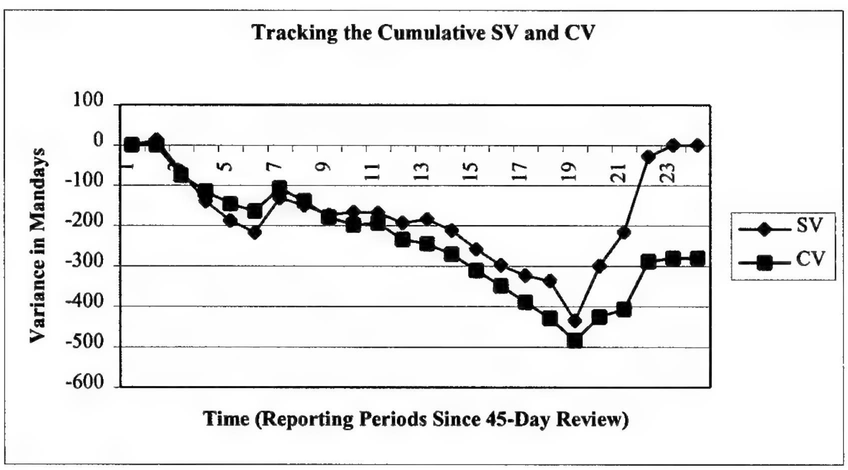

Figure 5.1 - Tracking Cumulative Cost and Schedule Variances

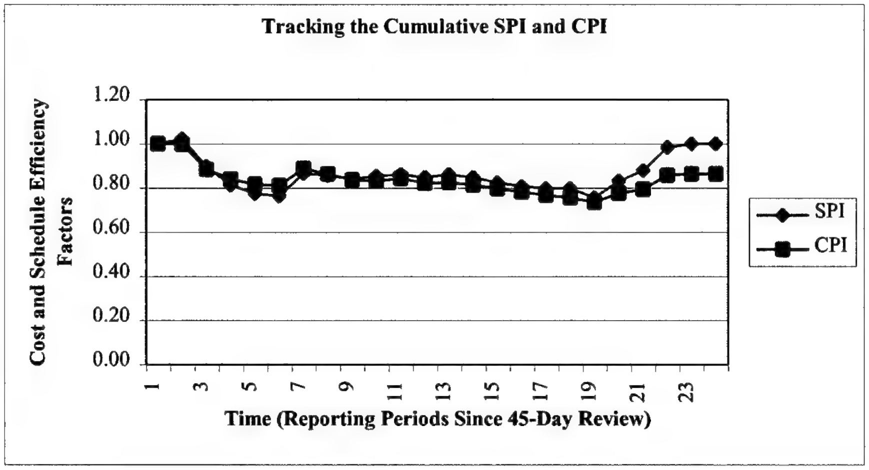

Figure 5.2 - Tracking Cumulative Performance Indices

The next area that was reviewed from the applied analysis techniques was the forecasting of an Estimate at Completion. With the final actual cost known, the accuracy of these predictions could be monitored. As can be expected, the Schedule Cost Index produced the highest values for projects behind schedule due to the multiplication factor of a SPI and CPI less than one. With a performance factor of 1.0, the lowest estimates were achieved, however this factor does not account for past performance efficiencies. Figure 5.3 displays the trend of the forecasts throughout the duration of one of the projects. The projected values in this example ended up higher than the final actual costs since the project was not completed within the deployment and was turned over to the relieving Battalion. By forecasting the EAC from past performance efficiency, a more accurate estimate of the mandays to be turned over to the relieving Battalion can be made.

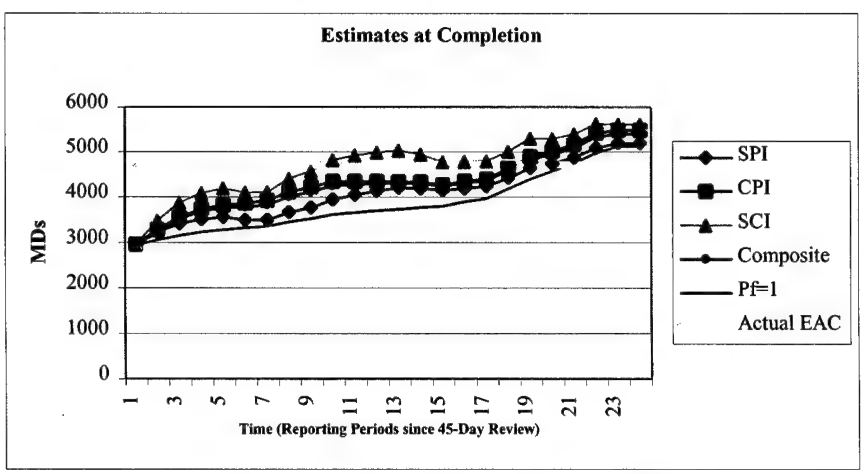

Figure 5.3 - Range of EAC Forecasts on NMCB Project

Having reviewed the application of the earned value techniques to these sample projects, the benefits of their use on NMCB projects can be observed. The greatest benefit is perhaps in the trend analysis that it affords management to avoid future problems and to monitor the results of implemented changes.

5.4 Obstacles to Implementation

With the implementation of any new management approach, obstacles are bound to be present. At times, a desire to maintain the "status quo" can prevent changes from occurring. Although, some of the basics concepts of earned value are utilized in NCF project management, the author believes that in establishing all of identified methods, techniques, and analysis tools the following obstacles may appear.

5.4.1 Training

In order to meet the mission identified for the Naval Construction Force, the various units continuously conduct training in the areas of military and construction proficiency. Just as earned value methodology evolved from simple concepts introduced by industrial engineers, to becoming an overbearing requirement implemented by the government, and finally reforming back into a more widely accepted standard, the implementation of earned value can probably expect similar results initially in the NCF. Until project crewleaders and management gain awareness and experience in the techniques identified, training will need to occur to expedite the learning process.

5.4.2 Accurate Accumulation of Data

Although timecard data is tracked and accumulated for each project, it is the author's experience that this is a time consuming process involving significant effort to ensure accuracy. As it currently stands, the timecard accounting system and the project management system are not integrated. Therefore, the successful application of earned value management would partly be based on management's ability to quickly gather required data for analysis when desired.

5.4.3 Revision of Deployment Tasking

As was identified, "rapid contingency response" is a key element of the NCF's mission. When called upon to provide this response, many of the resources that are assigned to on-going projects will be called upon to fulfill this mission. In order to maintain the validity of the earned value analysis, adjustments to the affected project's plan would need to be made.

5.4.4 Support of System

The implementation of an Earned Value Management System must be accepted by both project crewmembers as well as management to be fully successful. To achieve this, the benefits and knowledge gained through the analysis must be shared amongst all parties involved. Without this awareness and buy in by the lowest level team member, the implementation of earned value analysis and the gathering of data can appear as an added burden to the execution of a project.

Furthermore, the results of earned value analysis must be constructively examined as how to improve project performance and not individual performance. Otherwise, the possibility of data manipulation exists in an effort to avoid a poor individual evaluation. Through proper management focus and the introduction of earned value project management as a tool for improvement, vice another requirement that must be met, this challenge can be surpassed.

5.5 Summary

In summary, this chapter presented and reviewed the application of the described earned value analysis metrics to actual NCF projects. The methodology used in employing the concepts identified in this paper to the sample projects was discussed. Finally, probable obstacles to the successful introduction and implementation of the earned value management approach were presented.

6. Conclusions and Recommendations

6.1 Conclusions

Earned Value Management is a powerful tool that can assist the Naval Construction Force in the management of its construction projects. It enables the project team to identify problems and trends at an earlier stage, thereby allowing appropriate action to be taken. While it cannot be viewed as a solution to all project issues, it does provide a means to manage a project in an efficient way.

Through a review of the Naval Construction Force project fundamentals, some basic elements of Earned Value Management already exist. By adapting the procedures identified, the full benefits of all three data elements and the analysis tools they provide would be realized. From the application of Earned Value Management to the sample projects, the future tracking of variances and performance indices by the Naval Construction Force is recommended. Furthermore, the use of the forecasting tools provided by earned value analysis can aid in projecting the project status at the end of a deployment.

The successful implementation of earned value management is dependent upon properly adhering to many fundamental steps. Although obstacles may present themselves during this process, they are not insurmountable and with the proper management focus, acceptance from all team members can be expected.

6.2 Recommended Research

During the course of conducting this research the following issues were identified as recommended areas for future investigation:

- Follow the implementation of Earned Value Management through the full 14-month planning and deployment cycle of a Naval Mobile Construction Battalion. This will allow one to monitor its effectiveness at various stages and to gather additional data points for analysis.

- Software applications that integrate project management and accounting system data into an earned value management tool.

- Methods to validate the analysis metrics to detect if data manipulation has occurred in an effort to report higher progress then what was actually accomplished.

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APPENDIX A. Earned Value Management System Criteria

Organization

1. Define the authorized work elements for the program. A work breakdown structure (WBS), tailored for effective internal management control, is commonly used in this process.
2. Identify the program organizational structure including the major subcontractors responsible for accomplishing the authorized work, and define the organizational elements in which work will be planned and controlled.
3. Provide for the integration of the company's planning, scheduling, budgeting, work authorization and cost accumulation processes with each other, and as appropriate, the program work breakdown structure and the program organizational structure.
4. Identify the company organization or function responsible for controlling overhead (indirect costs).
5. Provide for integration of the program work breakdown structure and the program organizational structure in a manner that permits cost and schedule performance measurement by elements of either or both structures as needed.

Planning and Budgeting

6. Schedule the authorized work in a manner that describes the sequence of work and identifies significant task interdependencies required to meet the requirements of the program.
7. Identify physical products, milestones, technical performance goals, or other indicators that will be used to measure progress.
8. Establish and maintain a time-phased budget baseline, at the control account level, against which program performance can be measured. Budget for far-term efforts may be held in higher-level accounts until an appropriate time for allocation at the control account level. Initial budgets established for performance measurement will be based on either internal management goals or the external customer negotiated target cost including estimates for authorized but undefinitized work. On government contracts, if an over target baseline is used for performance measurement reporting purposes, prior notification must be provided to the customer.
9. Establish budgets for authorized work with identification of significant cost elements (labor, material, etc.) as needed for internal management and for control of subcontractors.
10. To the extent it is practical to identify the authorized work in discrete work packages, establish budgets for this work in terms of dollars, hours, or other measurable units. Where the entire control account is not subdivided into work packages, identify the far term effort in larger planning packages for budget and scheduling purposes.
11. Provide that the sum of all work package budgets plus planning package budgets within a control account equals the control account budget.

12. Identify and control level of effort activity by time-phased budgets established for this purpose. Only that effort which is immeasurable or for which measurement is impractical may be classified as level of effort.

13. Establish overhead budgets for each significant organizational component of the company for expenses, which will become indirect costs. Reflect in the program budgets, at the appropriate level, the amounts in overhead pools that are planned to be allocated to the program as indirect costs.

14. Identify management reserves and undistributed budget.

15. Provide that the program target cost goal is reconciled with the sum of all internal program budgets and management reserves.

Accounting Considerations

16. Record direct costs in a manner consistent with the budgets in a formal system controlled by the general books of account.

17. When a work breakdown structure is used, summarize direct costs from control accounts into the work breakdown structure without allocation of a single control account to two or more work breakdown structure elements.

18. Summarize direct costs from the control accounts into the contractor's organizational elements without allocation of a single control account to two or more organizational elements.

19. Record all indirect costs that will be allocated to the contract.

20. Identify unit costs, equivalent units costs, or lot costs when needed.

21. For EVMS, the material accounting system will provide for:

    (1) Accurate cost accumulation and assignment of costs to control accounts in a manner consistent with the budgets using recognized, acceptable, costing techniques.

    (2) Cost performance measurement at the point in time most suitable for the category of material involved, but no earlier than the time of progress payments or actual receipt of material.

    (3) Full accountability of all material purchased for the program including the residual inventory.

Analysis and Management Reports

22. At least on a monthly basis, generate the following information at the control account and other levels as necessary for management control using actual cost data from, or reconcilable with, the accounting system:

    (1) Comparison of the amount of planned budget and the amount of budget earned for work accomplished. This comparison provides the schedule variance.

(2) Comparison of the amount of the budget earned the actual (applied where appropriate) direct costs for the same work. This comparison provides the cost variance.

23. Identify, at least monthly, the significant differences between both planned and actual schedule performance and planned and actual cost performance, and provide the reasons for the variances in the detail needed by program management.

24. Identify budgeted and applied (or actual) indirect costs at the level and frequency needed by management for effective control, along with the reasons for any significant variances.

25. Summarize the data elements and associated variances through the program organization and/or work breakdown structure to support management needs and any customer reporting specified in the contract.

26. Implement managerial actions taken as the result of earned value information.

27. Develop revised estimates of cost at completion based on performance to date, commitment values for material, and estimates of future conditions. Compare this information with the performance measurement baseline to identify variances at completion important to company management and any applicable customer reporting requirements including statements of funding requirements.

Revisions and Data Maintenance

28. Incorporate authorized changes in a timely manner, recording the effects of such changes in budgets and schedules. In the directed effort prior to negotiation of a change, base such revisions on the amount estimated and budgeted to the program organizations.

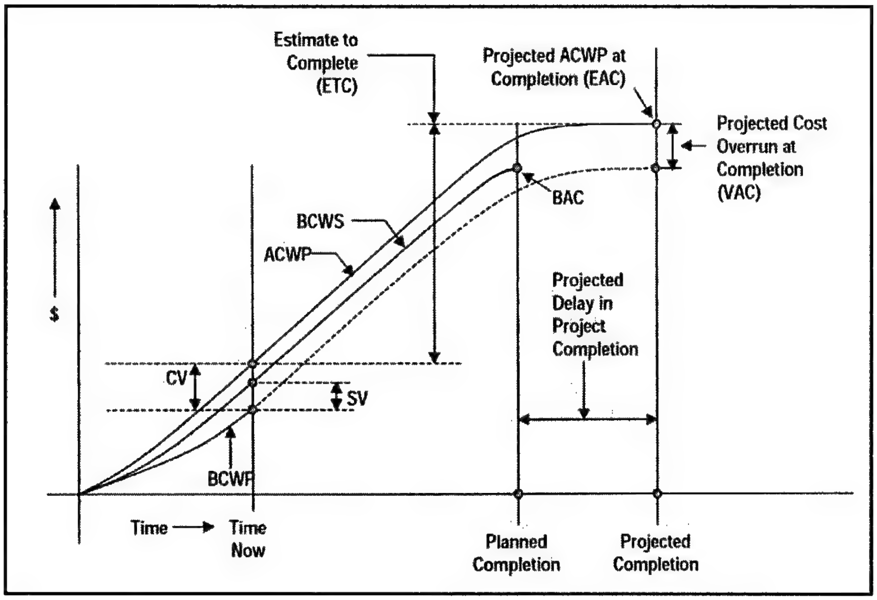
29. Reconcile current budgets to prior budgets in terms of changes to the authorized work and internal replanning in the detail needed by management for effective control.

30. Control retroactive changes to records pertaining to work performed that would change previously reported amounts for actual costs, earned value, or budgets. Adjustments should be made only for correction of errors, routine accounting adjustments, effects of customer or management directed changes, or to improve the baseline integrity and accuracy of performance measurement data.

31. Prevent revisions to the program budget except for authorized changes.

32. Document changes to the performance measurement baseline.

APPENDIX B. Earned Value Quick Reference Sheet



VARIANCES *(Favorable is positive, Unfavorable is negative)*

- **Cost Variance** $CV = BCWP - ACWP$ $CV\ \% = CV / BCWP$
- **Schedule Variance** $SV = BCWP - BCWS$ $SV\ \% = SV / BCWS$
- **Variance at Completion** $VAC = BAC - EAC$

PERFORMANCE INDICES *(Favorable is > 1.0, Unfavorable is < 1.0)*

- **Cost Efficiency** $CPI = BCWP / ACWP$
- **Schedule Efficiency** $SPI = BCWP / BCWS$

OVERALL STATUS

- **Percent Complete** $= \dfrac{BCWP_{CUM}}{BAC}$
- **Percent Spent** $= \dfrac{ACWP_{CUM}}{BAC}$

TO COMPLETE PERFORMANCE INDEX (TCPI)

$$TCPI_{(EAC)} = \frac{\text{WORK REMAINING}}{\text{COST REMAINING}} = \frac{BAC - BCWP_{CUM}}{EAC - ACWP_{CUM}}$$

ESTIMATE AT COMPLETION (EAC = ACWP + Estimate for Remaining Work)

$$EAC_{CPI} = \frac{BAC}{CPI_{CUM}}$$

- $EAC_{SCI} = ACWP_{CUM} + \dfrac{BAC - BCWP_{CUM}}{(CPI_{CUM}) \bullet (SPI_{CUM})}$

APPENDIX C. Results of Practical Application

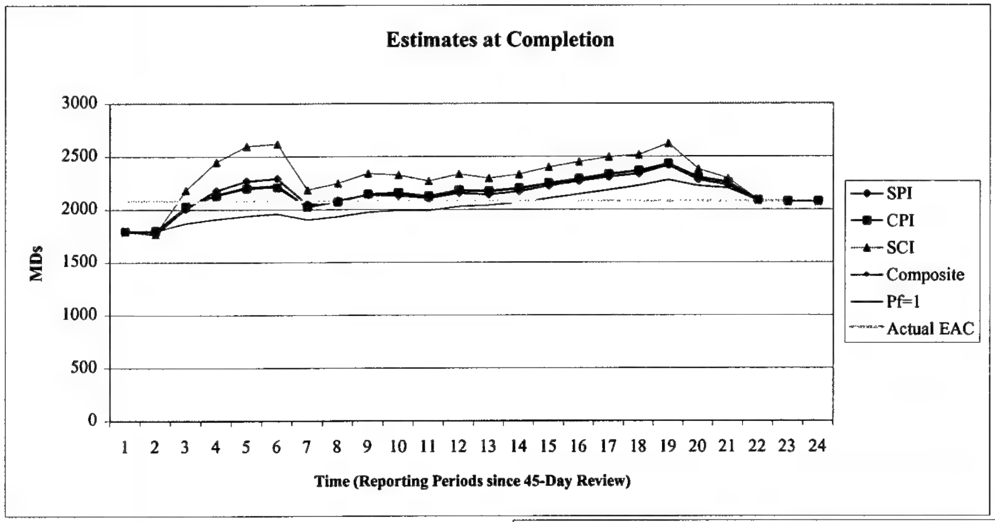
PSO-801 CONSTRUCT USO FACILITY

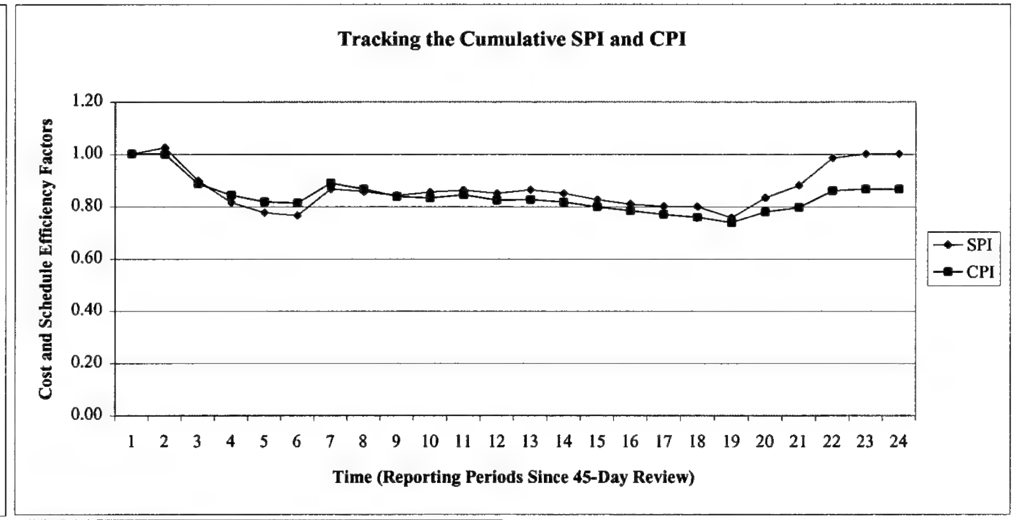
NMCB-7 % Tasked: 0 to 100.0%   Tasked MDs: 1,790

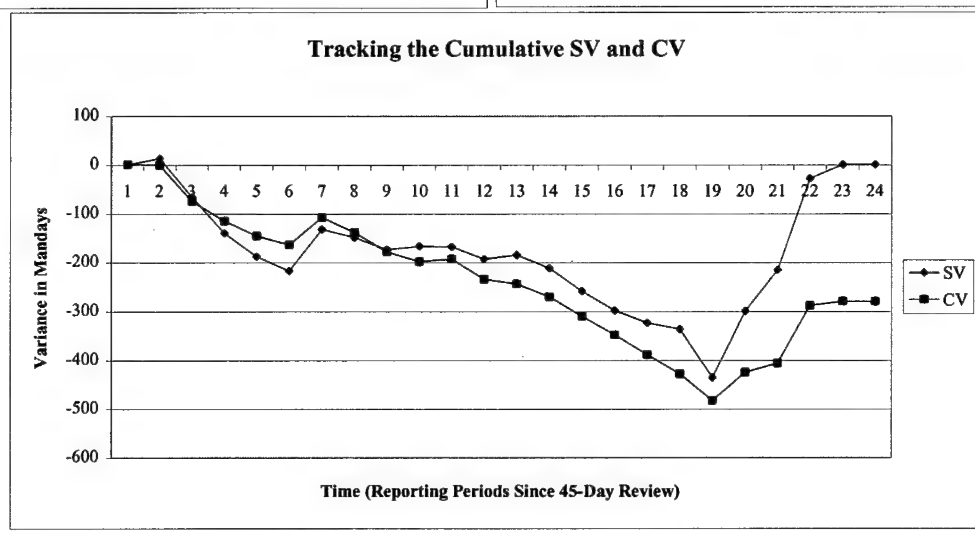
MA #	Master Activity	MDs	% WT	T/O	Oct-00			Nov-00				Dec-00				Jan-01					Feb-01				Mar-01				Apr-01					May	T/O
		Sch./Exp/Ernd.		MDs	16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	5	12	19	26	5	12	19	26	2	9	16	23	30	7	MDs
01xx	General	56 25 56	3.1% 100.0%	0																									56	 11	 8	 5 9	 20 28		
02xx	Site Work	50 13 50	2.8% 100.0%	0																							 8 18		50			 5 32			
03xx	Concrete	1 1 1	0.1% 100.0%	0							1 1 1																								
04xx	Masonry	129 91 129	7.2% 100.0%	0					10 10 10	11 11 11	35 35 35	36 22 67	19	18							 7 2	 6 4													
05xx	Metals	597 592 597	33.4% 100.0%	0	73 73 73	28 28 28	15 15 15	28 28 28	35 35 35	36 36 36	31 31 31	32 19 9	75 39 16	74 29 17	70 47 28	70 50 54	11 47 128	11 24 29	 27 13	 33 11	 12 21	 2	 14	 1	 3 3	 2 4	 2 2		8 3	 7 1					
06xx	Carpentry	79 120 79	4.4% 100.0%	0			10 10 10	18 18 18	5 5 5	6 6 6	2 2 2	2 19 11	14 32 6	15 23 11	 5		 10				7														
07xx	Moisture Protection	0 0 0	0.0% 0.0%	0																															
08xx	Doors, Windows, Glass	18 16 18	1.0% 100.0%	0											 4	 2	9 2	9 1						 1		 5					 1	 14 4			
09xx	Finishes	539 532 539	30.1% 100.0%	0													14	14	34 6 2	34 26 33	64 33 39	64 53 31	56 42 51	57 43 24	63 43 23	62 40 21	39 41 9	38 52 37	 40 12	 41 113	 40 31	 32 113			
10xx	Specialties	0 0 0	0.0% 0.0%	0																															
11xx	Architectural	0 0 0	0.0% 0.0%	0																															
12xx	Furnishings	0 0 0	0.0% 0.0%	0																															
13xx	Special	0 0 0	0.0% 0.0%	0																															
14xx	Conveying	0 0 0	0.0% 0.0%	0																															
15xx	Mechanical	158 307 158	8.8% 100.0%	0	6 6 6	9 9 9	4 4 4	4 4 4	23 ~~23~~ 23	22 22 22	11 11 11	11 35	 12	 6	17 7	17 10	3 18	2 28 2	 17 9	 12 7	 7 5	 9	3 8 3	4 4 7	3 6 1	2 8 2	9 6 1	8 9	 8	 9 1	 6 21	 3 20			
16xx	Electrical	163 374 163	9.1% 100.0%	0	6 6 6	17 17 17	8 8 8					 7	1 21 8	 15 5	 11 7	 13 3	21 23 4	21 19 8	18 17 3	17 7 7	 6 3	 10 4	4 31 3	4 17 5	11 18 3	11 23 3	12 19 5	12 23 8	 19 3	 21 10	 19 23	 11 10			
17xx	Expeditionary Structures	0 0 0	0.0% 0.0%	0																															
Total MD Scheduled		1790	100.0%																																
MDs Scheduled this Period					85	54	37	50	73	75	80	81	109	107	87	87	58	57	52	51	71	64	63	65	77	75	60	58	114	0	0	0	0	0	
Cumulative MDs Scheduled					85	139	176	226	299	374	454	535	644	751	838	925	983	1,040	1,092	1,143	1,214	1,278	1,341	1,406	1,483	1,558	1,618	1,676	1,790	1,790	1,790	1,790	1,790	1,790	
MDs Expended this Period					85	54	37	50	73	75	80	95	104	73	70	75	88	71	67	78	65	80	81	64	70	73	76	84	70	78	65	70	20	0	
Cumulative MDs Expended					85	139	176	226	299	374	454	549	653	726	796	871	959	1,030	1,097	1,175	1,240	1,320	1,401	1,465	1,535	1,608	1,684	1,768	1,838	1,916	1,981	2,051	2,071	2,071	
MDs Earned this Period					85	54	37	50	73	75	80	94	30	33	39	57	144	40	27	58	70	39	71	38	30	35	35	45	15	136	84	188	28	0	
Cumulative MDs Earned this Period				0	85	139	176	226	299	374	454	548	578	611	650	707	851	891	918	976	1,046	1,085	1,156	1,194	1,224	1,259	1,294	1,339	1,354	1,490	1,574	1,762	1,790	1,790	
MDs Remaining (Total Project)				1,790	1,705	1,651	1,614	1,564	1,491	1,416	1,336	1,242	1,212	1,179	1,140	1,083	939	899	872	814	744	705	634	596	566	531	496	451	436	300	216	28	0	0	
NMCB-5 Turnover MD's				0																															
NMCB-7 MDs Scheduled				1,790																															
NMCB-7 Turnover MDs scheduled				0																															
NMCB Project Total MDs				1790																															
Project % Scheduled				0.0%	4.7%	7.8%	9.8%	12.6%	16.7%	20.9%	25.4%	29.9%	36.0%	42.0%	46.8%	51.7%	54.9%	58.1%	61.0%	63.9%	67.8%	71.4%	74.9%	78.5%	82.8%	87.0%	90.4%	93.6%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	
Project % Complete (WIP)				0.0%	4.7%	7.8%	9.8%	12.6%	16.7%	20.9%	25.4%	30.6%	32.3%	34.1%	36.3%	39.5%	47.5%	49.8%	51.3%	54.5%	58.4%	60.6%	64.6%	66.7%	68.4%	70.3%	72.3%	74.8%	75.6%	83.2%	87.9%	98.4%	100.0%	100.0%	
Project % Expended				0.0%	4.7%	7.8%	9.8%	12.6%	16.7%	20.9%	25.4%	30.7%	36.5%	40.6%	44.5%	48.7%	53.6%	57.5%	61.3%	65.6%	69.3%	73.7%	78.3%	81.8%	85.8%	89.8%	94.1%	99%	103%	107%	111%	115%	116%	116%	

EARNED VALUE ANALYSIS

Schedule Variance	0	13	-66	-140	-188	-218	-132	-149	-174	-167	-168	-193	-165	-212	-259	-299	-324	-337	-436	-300	-216	-28	0	0
Schedule Variance %	0.0%	2.4%	-10.2%	-18.6%	-22.4%	-23.6%	-13.4%	-14.3%	-15.9%	-14.6%	-13.8%	-15.1%	-13.8%	-15.1%	-17.5%	-19.2%	-20.0%	-20.1%	-24.4%	-16.8%	-12.1%	-1.6%	0.0%	0.0%
Cost Variance	0	-1	-75	-115	-146	-164	-108	-139	-179	-199	-194	-235	-245	-271	-311	-349	-390	-429	-484	-426	-407	-289	-281	-281
Cost Variance %	0.0%	-0.2%	-13.0%	-18.8%	-22.5%	-23.2%	-12.7%	-15.6%	-19.5%	-20.4%	-18.5%	-21.7%	-21.2%	-22.7%	-25.4%	-27.7%	-30.1%	-32.0%	-35.7%	-28.6%	-25.9%	-16.4%	-15.7%	-15.7%
Schedule Performance Index	1.00	1.02	0.90	0.81	0.78	0.76	0.87	0.86	0.84	0.85	0.86	0.85	0.86	0.85	0.83	0.81	0.80	0.80	0.76	0.83	0.88	0.98	1.00	1.00
Cost Performance Index	1.00	1.00	0.89	0.84	0.82	0.81	0.89	0.87	0.84	0.83	0.84	0.82	0.83	0.82	0.80	0.78	0.77	0.76	0.74	0.78	0.79	0.86	0.86	0.86
Final Actual MDs Expended	2,071																							
Estimate at Completion $_{SPI}$	1790	1762	2003	2175	2266	2288	2044	2079	2134	2128	2103	2150	2136	2167	2221	2265	2304	2333	2414	2276	2227	2079	2071	2071
Estimate at Completion $_{CPI}$	1790	1793	2022	2127	2192	2205	2017	2069	2139	2155	2122	2178	2169	2196	2245	2286	2329	2363	2430	2302	2253	2084	2071	2071
Estimate at Completion $_{SCI}$	1790	1764	2179	2448	2596	2617	2181	2243	2337	2323	2264	2330	2292	2326	2395	2447	2491	2513	2620	2379	2290	2084	2071	2071
Estimate at Completion $_{Composite}$	1790	1787	2018	2136	2206	2221	2022	2071	2138	2150	2118	2172	2163	2190	2240	2282	2324	2357	2427	2296	2247	2083	2071	2071
Estimate at Completion $_{1}$	1790	1791	1865	1905	1936	1954	1898	1929	1969	1989	1984	2025	2035	2061	2101	2139	2180	2219	2274	2216	2197	2079	2071	2071
To-Complete Performance Index$_{EAC}$	1.00	1.00	0.89	0.84	0.82	0.81	0.89	0.87	0.84	0.83	0.84	0.82	0.83	0.82	0.80	0.78	0.77	0.76	0.74	0.78	0.79	0.86		
To-Complete Performance Index$_{BAC}$	1.00	1.00	1.07	1.11	1.15	1.18	1.13	1.18	1.26	1.32	1.35	1.50	1.63	1.83	2.22	2.92	4.68	20.50	-9.08	-2.38	-1.13	-0.11	0.00	0.00
Variance at Completion	0	-3	-232	-337	-402	-415	-227	-279	-349	-365	-332	-388	-379	-406	-455	-496	-539	-573	-640	-512	-463	-294	-281	-281
Variance at Completion %	0.0%	-0.2%	-13.0%	-16.8%	-22.5%	-23.2%	-12.7%	-15.6%	-19.5%	-20.4%	-18.5%	-21.7%	-21.2%	-22.7%	-25.4%	-27.7%	-30.1%	-32.0%	-35.7%	-28.6%	-25.9%	-16.4%	-15.7%	-15.7%


Estimates at Completion
MDs
3000
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (Reporting Periods since 45-Day Review)
SPI
CPI
SCI
Composite
Pf=1
Actual EAC


Tracking the Cumulative SPI and CPI
Cost and Schedule Efficiency Factors
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (Reporting Periods Since 45-Day Review)
SPI
CPI


Tracking the Cumulative SV and CV
Variance in Mandays
100
0
-100
-200
-300
-400
-500
-600
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (Reporting Periods Since 45-Day Review)
SV
CV

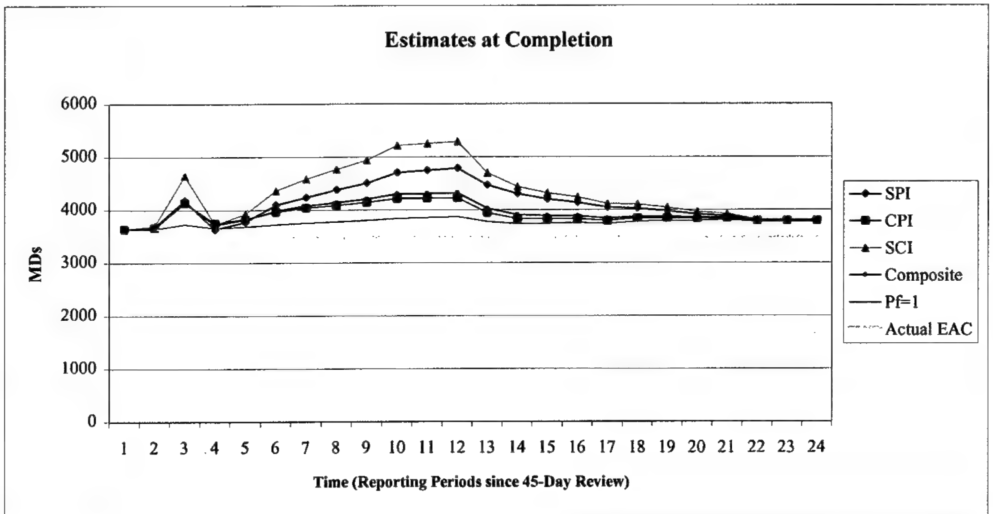
NV9-895 CATFISH #1 LEVEL II UPDATED: 28 APRIL 01

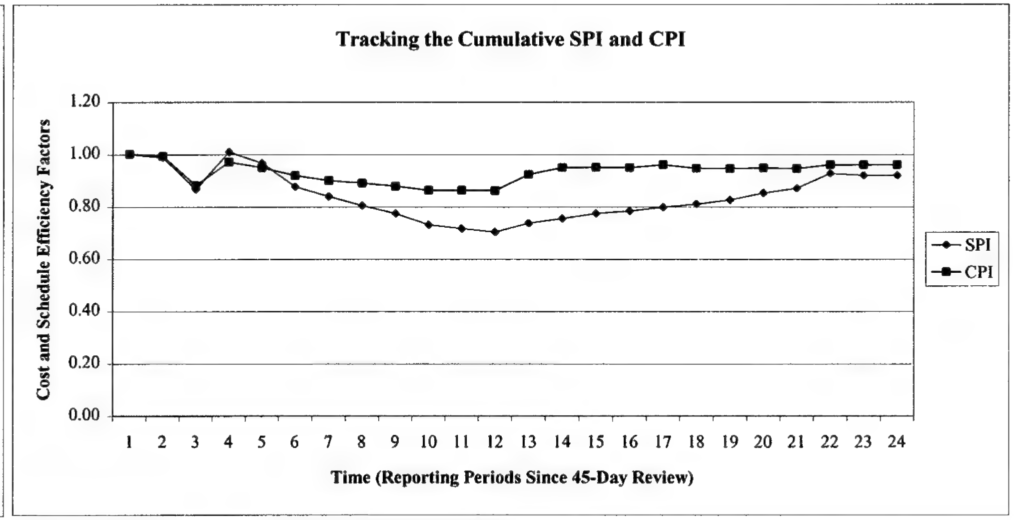
NMCB-7 % Tasked: 0 to 100.0% Tasked MDs: 3,623

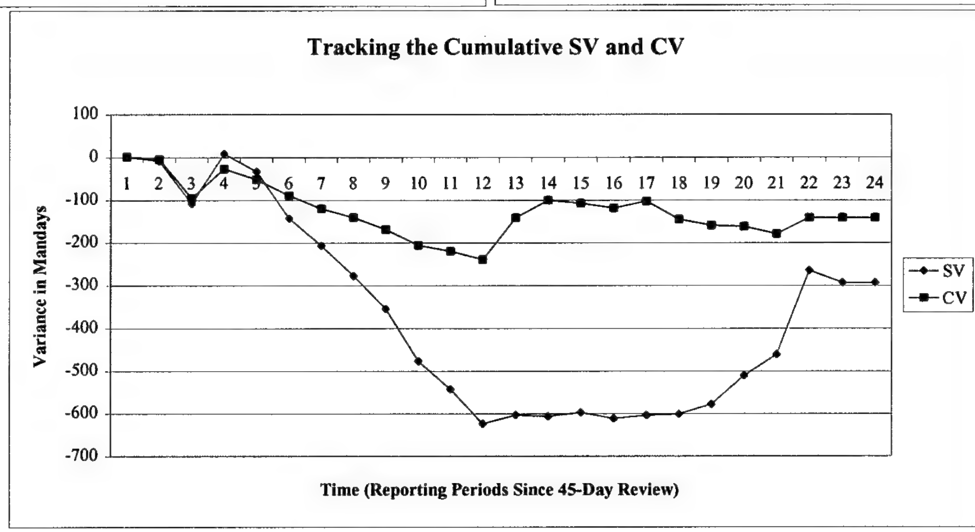
MA #	Master Activity	MDs Sch./Exp/Ernd.	% WT	T/O MDs	Oct-00			Nov-00				Dec-00				Jan-01					Feb-01				Mar-01				Apr-01					May	T/O MDs
					16	23	30	6	13	20	27	4	11	18	25	1	8	15	22	29	5	12	19	26	5	12	19	26	2	9	16	23	30	7	
01xx	General	41	1.1%		17																												24		
		17			17																														
		17	41.5%		17																														
02xx	Site Work	393	10.8%		50	9	34	13	21	30	1	14	21	17	16	15	19	20	18	17	11	10	12	11	11	9	6	8							
		382			50	9	34	13	21	30	1	0		4	11	6	11	0	0	12	11	22	13	20	18	17	6	13	0	20	20	20			
		373	94.9%		50	9	34	13	21	30	1	0		7	4	7	20	0	0	2	11	18	13	6	16	14	16	25	0	16	20	20			
03xx	Concrete	126	3.5%		22	21	4	13	27	0	2	0				22	14	1																	
		141			22	21	4	13	27	0	2	0				0	0														39	13			
		126	100.0%		22	21	4	13	27	0	2	0				0	0														33	4			
04xx	Masonry	77	2.1%																						13	26	21	17							
		83																											5	26	24	28			
		77	100.0%																										11	9	20	37			
05xx	Metals	84	2.3%		25	1	13	6	8	14	14	3																							
		84			25	1	13	6	8	14	14	3																							
		84	100.0%		25	1	13	6	8	14	14	3																							
06xx	Carpentry	70	1.9%										7	10	24	15			8	6															
		290												20	24	55	47	32	47	30	17	13	5												
		68	97.1%											3	3	13	15	10	16	3	3	1	1												
07xx	Moisture Protection	710	19.6%		0	9	27	33	26	37	69	66	76	49	48	49	39	36	27	25	25	25	25	19											
		706			0	9	27	33	26	37	69	77	98	98	55	20	17	12	11	8	11	13	4	5	11	6	5	29	12	13					
		679	95.6%		0	9	27	33	26	37	69	71	7	179	60	22	10	10	8	8	11	1	13	10	12	18	10	12	12	4					
08xx	Doors, Windows, Glass	186	5.1%		4	14	7												16	17	18	18	14				27	33	18						
		91			4	14	7										1	4	5	14	18	1	1									22			
		153	82.3%		4	14	7										1	3	16	14	18	1	1									74			
09xx	Finishes	589	16.3%																			56	67	72	71	92	76	66	30	30	29				
		888																				26	42	65	83	94	90	127	140	93	66	64			
		579	98.3%																			25	42	46	63	46	76	74	90	67	30	20			
10xx	Specialties	103	2.8%																									15	26	26	31	5			
		0																																	
		0	0.0%																																
11xx	Architectural	0	0.0%																																
		0																																	
		0	0.0%																																
12xx	Furnishings	12	0.3%																										6	6					
		0																																	
		0	0.0%																																
13xx	Special	0	0.0%																																
		0																																	
		0	0.0%																																
14xx	Conveying	0	0.0%																																
		0																																	
		0	0.0%																																
15xx	Mechanical	772	21.3%		2	9	11	13							21	25	38	38	51	93	76	57	50	52	51	38	15	5	40	27	30	25	5		
		393			2	9	11	13							3	4	12	13	21	27	17	26	27	29	44	45	37	20	5	10	7	11			
		740	95.9%		2	9	11	13							1	5	11	11	10	27	17	16	114	93	67	70	42	36	36	67	40	42			
16xx	Electrical	460	12.7%			12	3	1					3			31	24	34	34	38	17	17	17	31	21	25	21	28	34	35	34				
		396				12	3	1						1		0	13	17	21	20	21	21	16	24	27	25	19	29	29	32	34	31			
		432	93.9%			12	3	1						3		0	13	24	27	20	21	40	22	27	18	28	29	28	28	28	30	30			
17xx	Expeditionary Structures	0	0.0%																																
		0																																	
		0	0.0%																																
Total MD Scheduled		3623	100.0%																																
MDs Scheduled this Period					120	75	99	79	82	81	86	83	107	76	109	157	134	129	154	196	147	183	185	185	167	190	166	172	154	124	124	30	29	0	
Cumulative MDs Scheduled					120	195	294	373	455	536	622	705	812	888	997	1,154	1,288	1,417	1,571	1,767	1,914	2,097	2,282	2,467	2,634	2,824	2,990	3,162	3,316	3,440	3,564	3,594	3,623	3,623	
MDs Expended this Period					120	75	99	79	82	81	86	80	98	123	93	85	101	78	105	111	95	122	108	141	183	187	157	218	191	194	190	189	0	0	
Cumulative MDs Expended					120	195	294	373	455	536	622	702	800	923	1,016	1,101	1,202	1,280	1,385	1,496	1,591	1,713	1,821	1,962	2,145	2,332	2,489	2,707	2,898	3,092	3,282	3,471	3,471	3,471	
MDs Earned this Period					120	75	99	79	82	81	86	74	7	192	68	47	70	58	77	74	81	102	206	182	176	176	173	175	177	191	173	227	0	0	
Cumulative MDs Earned this Period				0	120	195	294	373	455	536	622	696	703	895	963	1,010	1,080	1,138	1,215	1,289	1,370	1,472	1,678	1,860	2,036	2,212	2,385	2,560	2,737	2,928	3,101	3,328	3,328	3,328	
MDs Remaining (Total Project)				3,623	3,503	3,428	3,329	3,250	3,168	3,087	3,001	2,927	2,920	2,728	2,660	2,613	2,543	2,485	2,408	2,334	2,253	2,151	1,945	1,763	1,587	1,411	1,238	1,063	886	695	522	295	295	295	
NMCB-5 Turnover MD's				0																															
NMCB-7 MDs Scheduled				3,623																															
NMCB-7 Turnover MDs scheduled				0																															
NMCB Project Total MDs				3623																															
Project % Scheduled				0.0%	3.3%	5.4%	8.1%	10.3%	12.6%	14.8%	17.2%	19.5%	22.4%	24.5%	27.5%	31.9%	35.6%	39.1%	43.4%	48.8%	52.8%	57.9%	63.0%	68.1%	72.7%	77.9%	82.5%	87.3%	91.5%	94.9%	98.4%	99.2%	100.0%	100.0%	
Project % Complete (WIP)				0.0%	3.3%	5.4%	8.1%	10.3%	12.6%	14.8%	17.2%	19.2%	19.4%	24.7%	26.6%	27.9%	29.8%	31.4%	33.5%	35.6%	37.8%	40.6%	46.3%	51.3%	56.2%	61.1%	65.8%	70.7%	75.5%	80.8%	85.6%	91.9%	91.9%	91.9%	
Project % Expended				0.0%	3.3%	5.4%	8.1%	10.3%	12.6%	14.8%	17.2%	19.4%	22.1%	25.5%	28.0%	30.4%	33.2%	35.3%	38.2%	41.3%	43.9%	47.3%	50.3%	54.2%	59.2%	64.4%	68.7%	75%	80%	85%	91%	96%	96%	96%	

EARNED VALUE ANALYSIS

	Nov 27	Dec 4	Dec 11	Dec 18	Dec 25	Jan 1	Jan 8	Jan 15	Jan 22	Jan 29	Feb 5	Feb 12	Feb 19	Feb 26	Mar 5	Mar 12	Mar 19	Mar 26	Apr 2	Apr 9	Apr 16	Apr 23	Apr 30	May 7
Schedule Variance	0	-9	-109	7	-34	-144	-208	-279	-356	-478	-544	-625	-604	-607	-598	-612	-605	-602	-579	-512	-463	-266	-295	-296
Schedule Variance %	0.0%	-1.3%	-13.4%	0.8%	-3.4%	-12.5%	-16.1%	-19.7%	-22.7%	-27.1%	-28.4%	-29.8%	-26.5%	-24.6%	-22.7%	-21.7%	-20.2%	-19.0%	-17.5%	-14.9%	-13.0%	-7.4%	-8.1%	-8.1%
Cost Variance	0	-6	-97	-28	-53	-91	-122	-142	-170	-207	-221	-241	-143	-102	-109	-120	-104	-147	-161	-164	-181	-143	-143	-143
Cost Variance %	0.0%	-0.9%	-13.8%	-3.1%	-5.5%	-9.0%	-11.3%	-12.5%	-14.0%	-16.1%	-16.1%	-16.4%	-8.5%	-5.5%	-5.4%	-5.4%	-4.4%	-5.7%	-5.9%	-5.6%	-5.8%	-4.3%	-4.3%	-4.3%
Schedule Performance Index	1.00	0.99	0.87	1.01	0.97	0.88	0.84	0.80	0.77	0.73	0.72	0.70	0.74	0.75	0.77	0.78	0.80	0.81	0.83	0.85	0.87	0.93	0.92	0.92
Cost Performance Index	1.00	0.99	0.88	0.97	0.96	0.92	0.90	0.89	0.88	0.86	0.86	0.86	0.92	0.95	0.95	0.95	0.96	0.95	0.94	0.95	0.94	0.96	0.96	0.96
Final Actual MDs Expended	3,471																							
Estimate at Completion $_{SPI}$	3623	3667	4173	3630	3770	4087	4235	4374	4499	4696	4739	4777	4466	4300	4198	4133	4041	4020	3971	3909	3882	3790	3792	3792
Estimate at Completion $_{CPI}$	3623	3654	4123	3736	3822	3949	4032	4075	4130	4205	4207	4216	3932	3822	3817	3820	3781	3831	3836	3826	3834	3779	3779	3779
Estimate at Completion $_{SCI}$	3623	3692	4638	3714	3921	4356	4577	4760	4934	5209	5246	5279	4692	4429	4308	4231	4109	4096	4035	3954	3917	3803	3806	3806
Estimate at Completion $_{Composite}$	3623	3657	4133	3714	3812	3976	4071	4130	4196	4291	4299	4311	4021	3901	3881	3873	3826	3864	3860	3841	3843	3781	3781	3781
Estimate at Completion $_1$	3623	3629	3720	3651	3676	3714	3745	3765	3793	3830	3844	3864	3766	3725	3732	3743	3727	3770	3784	3787	3804	3766	3766	3766
To-Complete Performance Index$_{EAC}$	1.00	0.99	0.88	0.97	0.95	0.92	0.90	0.89	0.88	0.86	0.86	0.86	0.92	0.96	0.96	0.95	0.96	0.95	0.94	0.95	0.94	0.96	0.96	0.96
To-Complete Performance Index$_{BAC}$	1.00	1.00	1.03	1.01	1.02	1.04	1.05	1.06	1.08	1.10	1.11	1.13	1.08	1.06	1.07	1.09	1.09	1.16	1.22	1.31	1.53	1.94	1.94	1.94
Variance at Completion	0	-31	-500	-113	-199	-326	-409	-452	-507	-582	-584	-593	-309	-199	-194	-197	-158	-208	-213	-203	-211	-156	-156	-156
Variance at Completion %	0.0%	-0.9%	-13.8%	-3.1%	-5.5%	-9.0%	-11.3%	-12.5%	-14.0%	-16.1%	-16.1%	-16.4%	-8.5%	-5.5%	-5.4%	-5.4%	-4.4%	-5.7%	-5.9%	-5.6%	-5.8%	-4.3%	-4.3%	-4.3%


Estimates at Completion
MDs
6000
5000
4000
3000
2000
1000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (Reporting Periods since 45-Day Review)
SPI
CPI
SCI
Composite
Pf=1
Actual EAC


Tracking the Cumulative SPI and CPI
Cost and Schedule Efficiency Factors
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (Reporting Periods Since 45-Day Review)
SPI
CPI

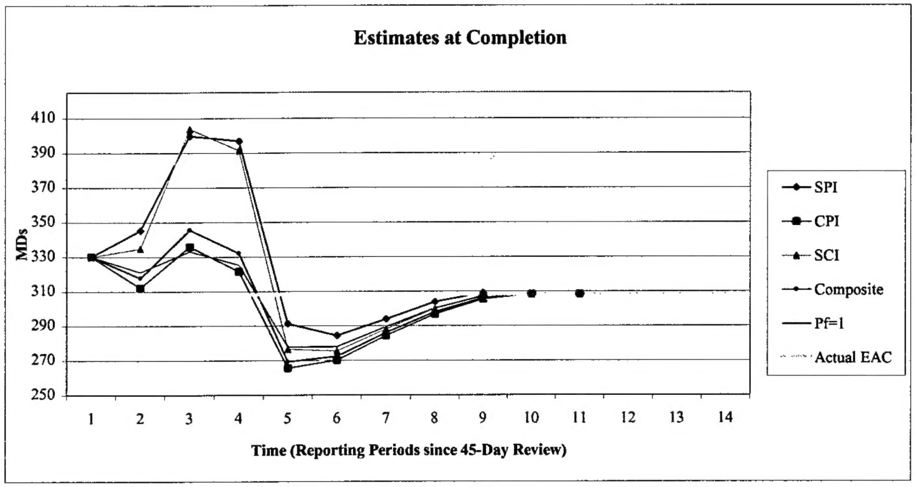

Tracking the Cumulative SV and CV
Variance in Mandays
100
0
-100
-200
-300
-400
-500
-600
-700
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time (Reporting Periods Since 45-Day Review)
SV
CV

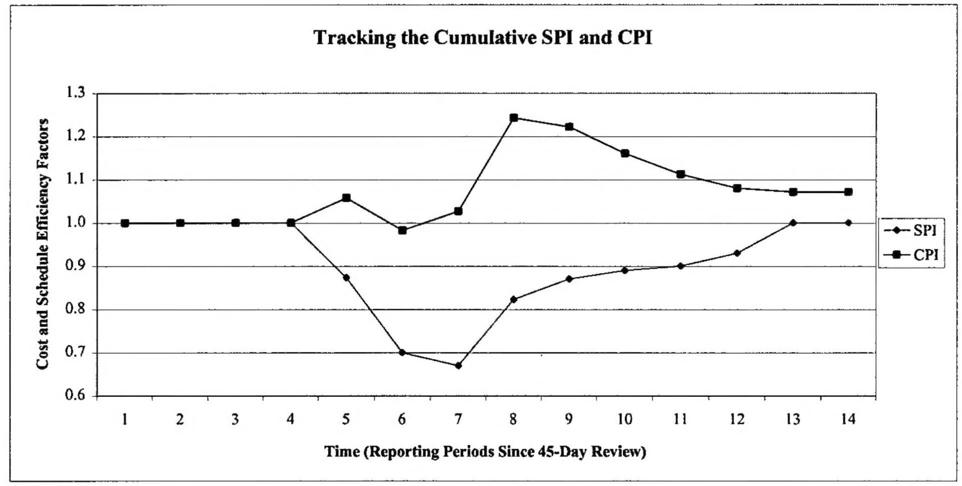
NMCB FOUR - NMCB FOUR Main Body

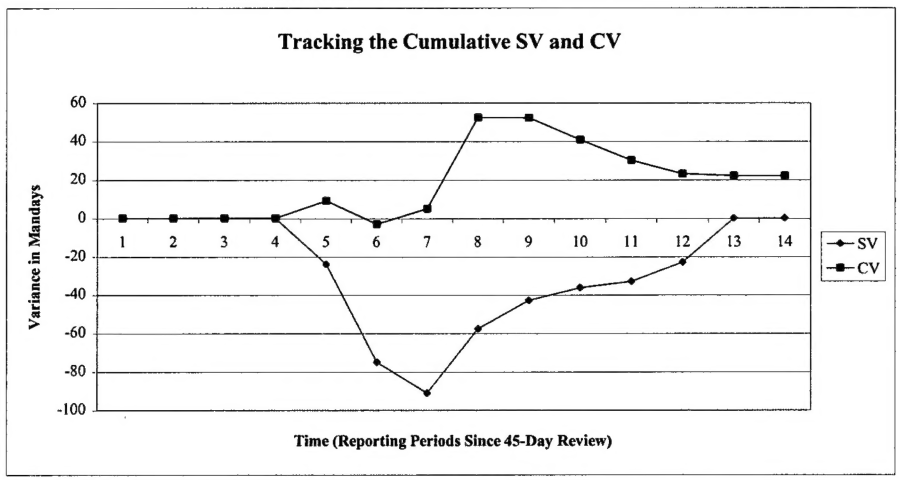
Manday Equivalent (ME) = 1.125 Availability Factor (AF) = 0.75

JK0-843	HAZMAT STORAGE FACILITY			LEVEL II Crewleader: BU2 RYAN							Prime Co: CHARLIE		TOTAL PROJECT MDs EST: 330 NMCB FOUR TASKED MDs: 330					
ACT #	ACTIVITY TITLE	MD	WT %	OCT 18-31	NOV 1-15	NOV 16-30	DEC 1-15	DEC 16-31	JAN 1-15	JAN 16-31	FEB 1-15	FEB 16-28	MAR 1-15	MAR 16-31	APR 1-15	APR 16-30	MAY 1-15	T/O
100	GENERAL	63 *54*	19%	43 *43*							15	5		*3*		*8*		
200	SITE WORK	27 *46*	8%	4 *4*	6 *6*	4 *4*	4 *4*				9 *1*		*11*	*4*	*2*	*10*		
300	CONCRETE	172 *158*	52%	4 *4*	22 *22*	12 *12*	24 *24*	45 *14*	35 *22*	18 *2*	12 *31*	*20*	*7*					
400	MASONRY	41 *19*	12%				9 *9*	12 *10*	20									
800	DOORS AND WINDOWS	14 *15*	4%						6	8	*3*			*7*	*5*			
900	FINISHES	12 *15*	4%								12				*9*	*6*		
1500	MECHANICAL	1 *1*	0%								1				*1*			
		0 *0*	0%															
		0 *0*	0%															
		0 *0*	0%															
		0 *0*	0%															
		0 *0*	0%															
		0 *0*	0%															
		0 *0*	0%															
	TURNOVER MDs CUMULATIVE MDs	0 *0*	0%															
Mandays Scheduled This Period				51	28	16	37	57	61	26	49	5	0	0	0	0	0	0
Cummulative Mandays Scheduled				51	79	95	132	189	250	276	325	330	330	330	330	330	330	330
Percent Complete Scheduled (Plot)			0%	15%	24%	29%	40%	57%	76%	84%	98%	100%	100%	100%	100%	100%	100%	100%
Mandays Earned This Period				51	28	16	37	33	10	10	83	20	7	3	10	23	0	
Cummulative Mandays Earned				51	79	95	132	165	175	185	267	287	294	297	307	330	330	
Actual WIP (Plot)			0%	15%	24%	29%	40%	50%	53%	56%	81%	87%	89%	90%	93%	100%	100%	
Mandays Expended This Period				51	28	16	37	24	22	2	35	20	18	14	17	24	0	
Cummulative Mandays Expended			0	51	79	95	132	156	178	180	215	235	253	267	284	308	308	
Percent Mandays Expended				15%	24%	29%	40%	47%	54%	55%	65%	71%	77%	81%	86%	93%	93%	
Mandays of Tasked Work Remaining*				330	279	251	235	198	165	155	145	63	43	36	33	23	0	
Current Working Estimate (Expended+Remaining)*				330	330	330	330	330	321	333	325	278	278	289	300	307	308	
Manday Efficiency This Period (%)				100%	100%	100%	100%	138%	45%	495%	236%	99%	37%	24%	58%	96%		
Percent Ahead/Behind This Period				0%	0%	0%	0%	-42%	-84%	-62%	68%	296%						
Cumulative Percent Ahead/Behind				0%	0%	0%	0%	-7%	-23%	-28%	-17%	-13%	-11%	-10%	-7%	0%		
Direct Labor Assigned This Period				6	6	6	6	6	6	6	6	6						
Workdays Scheduled This Period				11	11	10	12	10	10	5	9	9	12	12	10	10	0	
Manday Capability This Period				56	56	51	`	51	51	25	46	46						

	OCT 18-31	NOV 1-15	NOV 16-30	DEC 1-15	DEC 16-31	JAN 1-15	JAN 16-31	FEB 1-15	FEB 16-28	MAR 1-15	MAR 16-31	APR 1-15	APR 16-30	MAY 1-15	T/O
Schedule Variance	0	0	0	0	-24	-75	-91	-58	-43	-36	-33	-23	0	0	
Schedule Variance %															
Cost Variance	0	0	0	0	9	-3	5	52	52	41	30	23	22	22	
Cost Variance %															
Schedule Performance Index	1.0	1.0	1.0	1.0	0.9	0.7	0.7	0.8	0.9	0.9	0.9	0.9	1.0	1.0	
Cost Performance Index	1.0	1.0	1.0	1.0	1.1	1.0	1.0	1.2	1.2	1.2	1.1	1.1	1.1	1.1	
Estimate at Completion $_{SPI}$	330	330	330	330	345	400	397	291	284	294	304	309	308	308	
Estimate at Completion $_{CPI}$	330	330	330	330	312	336	321	265	270	284	297	305	308	308	
Estimate at Completion $_{SCI}$	330	330	330	330	335	404	391	276	275	288	300	307	308	308	
Estimate at Completion $_{Composite}$	330	330	330	330	318	345	332	269	272	286	298	306	308	308	
Estimate at Completion $_{1}$	330	330	330	330	321	333	325	278	278	289	300	307	308	308	


Estimates at Completion
MDs
410
390
370
350
330
310
290
270
250
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (Reporting Periods since 45-Day Review)
SPI
CPI
SCI
Composite
Pf=1
Actual EAC


Tracking the Cumulative SPI and CPI
Cost and Schedule Efficiency Factors
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (Reporting Periods Since 45-Day Review)
SPI
CPI


Tracking the Cumulative SV and CV
Variance in Mandays
60
40
20
0
-20
-40
-60
-80
-100
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (Reporting Periods Since 45-Day Review)
SV
CV

NMCB FOUR - NMCB FOUR Main Body

Manday Equivalent (ME) = 1.125 Availability Factor (AF) = 0.75

JK9-834 CONSTRUCT HEAD FACILITIES

LEVEL II

Crewleader: SW1 BURLIE

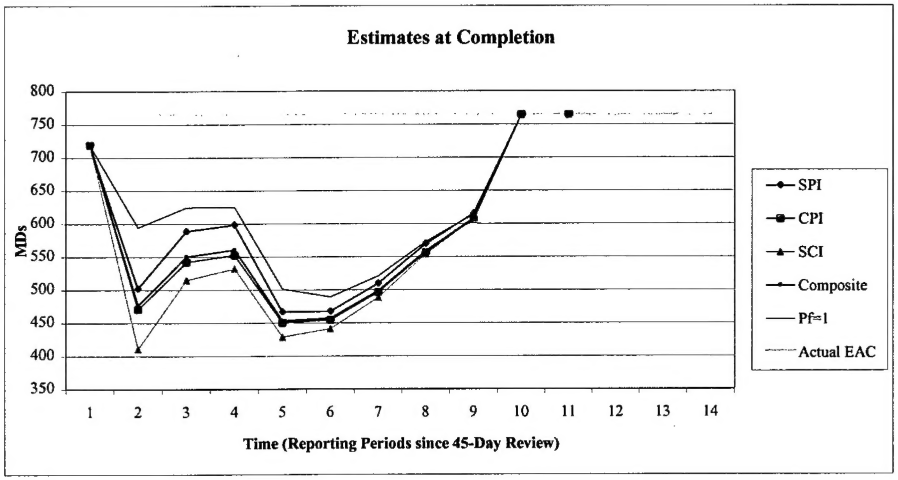
Prime Co: CHARLIE

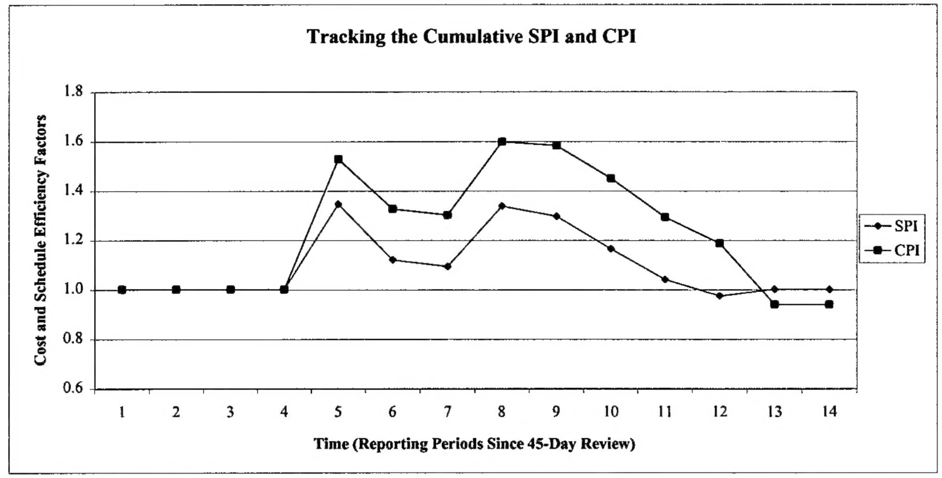
TOTAL PROJECT MDs EST: 718

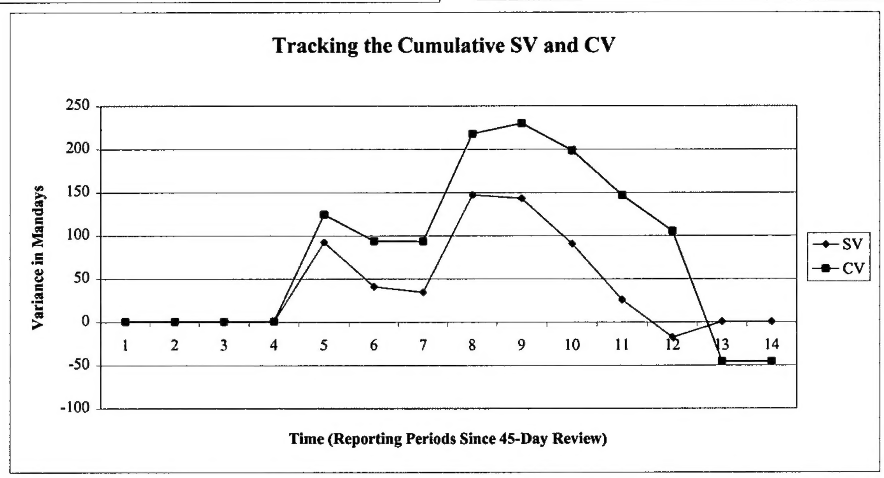
NMCB FOUR TASKED MDs: 718

ACT #	ACTIVITY TITLE	MD	WT %	OCT 18-31	NOV 1-15	NOV 16-30	DEC 1-15	DEC 16-31	JAN 1-15	JAN 16-31	FEB 1-15	FEB 16-28	MAR 1-15	MAR 16-31	APR 1-15	APR 16-30	MAY 1-15	T/O
100	GENERAL	98	14%	55											11	32		
		78		*55*												*23*		
200	SITEWORK	138	19%	9	10	27		19	21	12								
		92		*9*	*10*	*27*		*16*			*2*	*1*			40	*27*		
300	CONCRETE	357	50%	4	24		67	52	52	16	11	47	50	34				
		404		*4*	*24*		*67*	*23*	*52*	*22*	*7*	*28*	*40*	*56*	*57*	*24*		
400	MASONRY	56	8%								56							
		48									*46*	*2*						
800	DOORS AND WINDOWS	11	2%												11			
		10											*3*	*2*	*2*	*3*		
900	FINISHES	49	7%										17	32				
		125											*3*	*1*	*4*	*117*		
1500	MECHANICAL	9	1%											6	3			
		7														*7*		
		0	0%															
		0																
		0	0%															
		0																
		0	0%															
		0																
		0	0%															
		0																
		0	0%															
		0																
		0	0%															
		0																
		0	0%															
		0																
	TURNOVER MDs	0	0%															
	CUMULATIVE MDs	*0*																
Mandays Scheduled This Period				68	34	27	67	71	73	28	67	47	67	72	65	32	0	0
Cummulative Mandays Scheduled				68	102	129	196	267	340	368	435	482	549	621	686	718	718	718
Percent Complete Scheduled (Plot)			0%	9%	14%	18%	27%	37%	47%	51%	61%	67%	76%	86%	96%	100%	100%	100%
Mandays Earned This Period				68	34	27	67	163	22	22	180	43	14	7	22	50	0	
Cummulative Mandays Earned				68	102	129	196	359	381	402	582	625	639	646	668	718	718	
Actual WIP (Plot)			0%	9%	14%	18%	27%	50%	53%	56%	81%	87%	89%	90%	93%	100%	100%	
Mandays Expended This Period				68	34	27	67	39	52	22	55	31	46	59	63	201	0	
Cummulative Mandays Expended		0		68	102	129	196	235	287	309	364	395	441	500	563	764	764	
Percent Mandays Expended				9%	14%	18%	27%	33%	40%	43%	51%	55%	61%	70%	78%	106%	106%	
Mandays of Tasked Work Remaining*				718	650	616	589	522	359	337	316	136	93	79	72	50	0	
Current Working Estimate (Expended+Remaining)*				718	718	718	718	718	594	624	625	500	488	520	572	613	764	
Manday Efficiency This Period (%)				100%	100%	100%	100%	418%	41%	98%	326%	139%	31%	12%	34%	25%		
Percent Ahead/Behind This Period				0%	0%	0%	0%	130%	-70%	-23%	168%	-8%	-79%	-90%	-67%	57%		
Cumulative Percent Ahead/Behind				0%	0%	0%	0%	13%	6%	5%	20%	20%	13%	4%	-3%	0%		
Direct Labor Assigned This Period				6	6	6	6	6	6	6	6	6						
Workdays Scheduled This Period				11	11	10	12	10	10	5	9	9	12	12	10	10	0	
Manday Capability This Period				56	56	51	.	51	51	25	46	46						

	OCT 18-31	NOV 1-15	NOV 16-30	DEC 1-15	DEC 16-31	JAN 1-15	JAN 16-31	FEB 1-15	FEB 16-28	MAR 1-15	MAR 16-31	APR 1-15	APR 16-30	MAY 1-15	T/O
Schedule Variance	0	0	0	0	92	41	34	147	143	90	25	-18	0	0	
Schedule Variance %															
Cost Variance	0	0	0	0	124	94	93	218	230	198	146	105	-46	-46	
Cost Variance %															
Schedule Performance Index	1.0	1.0	1.0	1.0	1.3	1.1	1.1	1.3	1.3	1.2	1.0	1.0	1.0	1.0	
Cost Performance Index	1.0	1.0	1.0	1.0	1.5	1.3	1.3	1.6	1.6	1.4	1.3	1.2	0.9	0.9	
Estimate at Completion $_{SPI}$	718	718	718	718	502	589	598	466	467	509	569	615	764	764	
Estimate at Completion $_{CPI}$	718	718	718	718	470	542	552	449	454	496	556	605	764	764	
Estimate at Completion $_{SCI}$	718	718	718	718	410	514	531	428	441	488	553	607	764	764	
Estimate at Completion $_{Composite}$	718	718	718	718	476	550	560	452	456	498	558	607	764	764	
Estimate at Completion $_{1}$	718	718	718	718	594	624	625	500	488	520	572	613	764	764	


Estimates at Completion
MDs
800
750
700
650
600
550
500
450
400
350
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (Reporting Periods since 45-Day Review)
SPI
CPI
SCI
Composite
Pf=1
Actual EAC


Tracking the Cumulative SPI and CPI
Cost and Schedule Efficiency Factors
1.8
1.6
1.4
1.2
1.0
0.8
0.6
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (Reporting Periods Since 45-Day Review)
SPI
CPI


Tracking the Cumulative SV and CV
Variance in Mandays
250
200
150
100
50
0
-50
-100
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Time (Reporting Periods Since 45-Day Review)
SV
CV